ERDC TR-16-2

Engineer Research and Development Center

US Army Corps of Engineers®
Engineer Research and Development Center

ERDC
INNOVATIVE SOLUTIONS for a safer, better world

Ocean Dredged Material Disposal Site (ODMDS) Authorization and Short-Term FATE (STFATE) Model Analysis

2014 – 2015 Working Group Findings Report

Jase D. Ousley, Paul R. Schroeder, Susan Bailey, Matthew J. Lang, and Alan Kennedy

March 2016

Split hull hopper at ocean dredged material disposal site

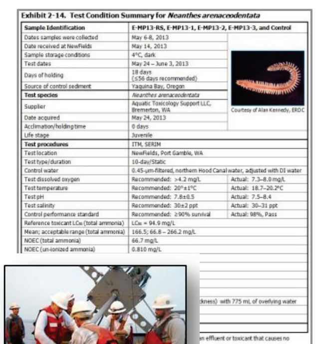
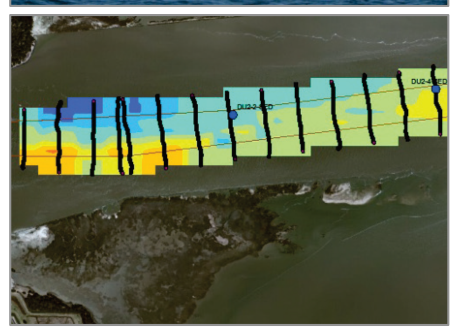


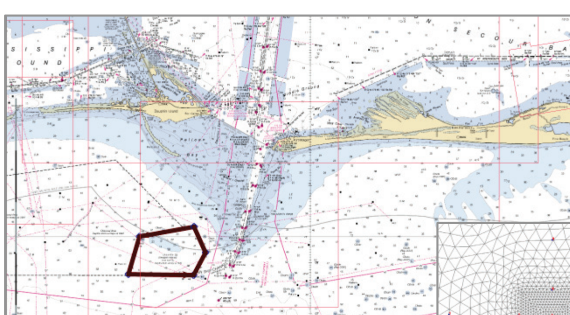
Exhibit 2-14. Test Condition Summary for *Neanthes arenaceodentata*

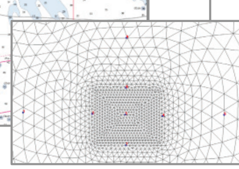
Sample Identification	E-MP13-RS, E-MP13-1, E-MP13-2, E-MP13-3, and Control	
Dates samples were collected	May 6-8, 2013	
Date received at NewFields	May 14, 2013	
Sample storage conditions	4°C, dark	
Test dates	May 24 – June 3, 2013	
Days of holding	18 days (≤56 days recommended)	
Source of control sediment	Yaquina Bay, Oregon	
Test species	*Neanthes arenaceodentata*	
Supplier	Aquatic Toxicology Support LLC, Bremerton, WA	Courtesy of Alan Kennedy, ERDC
Date acquired	May 24, 2013	
Acclimation/holding time	0 days	
Life stage	Juvenile	
Test procedures	ITM, SERIM	
Test location	NewFields, Port Gamble, WA	
Test type/duration	10-day/Static	
Control water	0.45-µm-filtered, northern Hood Canal water, adjusted with DI water	
Test dissolved oxygen	Recommended: >4.2 mg/L	Actual: 7.3–8.0 mg/L
Test temperature	Recommended: 20°±1°C	Actual: 18.7–20.2°C
Test pH	Recommended: 7.8±0.5	Actual: 7.5–8.4
Test salinity	Recommended: 30±2 ppt	Actual: 30–31 ppt
Control performance standard	Recommended: ≥90% survival	Actual: 98%, Pass
Reference toxicant LC_{50} (total ammonia)	LC_{50} = 94.9 mg/L	
Mean; acceptable range (total ammonia)	166.5; 66.8 – 266.2 mg/L	
NOEC (total ammonia)	66.7 mg/L	
NOEC (un-ionized ammonia)	0.810 mg/L	

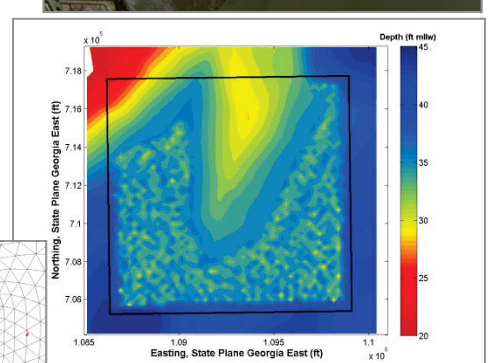
…dkness) with 775 mL of overlying water

…an effluent or toxicant that causes no









Approved for public release; distribution is unlimited.

ERDC TR-16-2
March 2016

Ocean Dredged Material Disposal Site (ODMDS) Authorization and Short-Term FATE (STFATE) Model Analysis

2014 – 2015 Working Group Findings Report

Jase D. Ousley

Coastal and Hydraulics Laboratory
U.S. Army Engineer Research and Development Center
3909 Halls Ferry Rd, Building 3200
Vicksburg, MS 39180-6199

Paul R. Schroeder, Susan Bailey, and Alan Kennedy

Environmental Laboratory
U.S. Army Engineer Research and Development Center
3909 Halls Ferry Rd, Building 3270
Vicksburg, MS 39180-6199

Matthew J. Lang

Mobile Engineer District
U.S. Army Corps of Engineers
109 St. Joseph Street
Mobile, AL 36602

Final report

Approved for public release; distribution is unlimited.

Prepared for U.S. Army Corps of Engineers
Washington, DC 20314-1000

Abstract

The U.S. Army Corps of Engineers (USACE) dredges millions of cubic yards of sediment from Federal ports, harbors, and waterways annually. The USACE Navigation Data Center reports on average 42% of dredged material is placed in Offshore Dredged Material Disposal Sites (ODMDS). Regulation of dredged material placement within waters of the United States and ocean waters is a shared responsibility of the USACE and U.S. Environmental Protection Agency (USEPA) under the Marine Protection, Research, and Sanctuaries Act (MPRSA, also called the Ocean Dumping Act) and the Clean Water Act (CWA). Dredged sediments placed offshore must have limited contaminants and be shown to have minimal impact on benthic species. The Short-Term FATE of dredged material placed in open water (STFATE) model was created by USACE to assist with dredge material placement impact assessment. STFATE enables the computation of the movement of dredged material disposed in open water as it falls through a water column and is transported by the ambient current. In 2013, STFATE model outputs resulted in operational restrictions on several projects in USACE South Atlantic Division (SAD) districts. A working group was set up to address operational controls such as dredging-vessel bin-load restrictions, confined release zones and other issues that impacted dredging efficiency and cost. Evaluation of the sensitivity of STFATE model inputs found grid cell size, dredge vessel velocity and heading, water density gradient, and application factors had significant impacts on model output. The working group found that applying a more specific, technically defensible application factor produced model outputs that result in less restricted dredging operations in USACE Mobile District, Mobile Harbor O&M project. Given the positive outcomes from the Mobile District, it is recommended that other USACE projects with operational restrictions undergo STFATE re-evaluation. Finally, as projects require a new MPRSA and CWA concurrence from USEPA, it is recommended that the findings herein be applied.

Contents

Abstract ii

Figures and Tables iv

Preface v

1 Introduction 1

1.1 Background 1
1.2 Ocean Dredged Material Disposal Sites (ODMDS) 2
1.3 Baseline information 2
1.4 Objectives 5

2 STFATE Model Analysis 6

2.1 STFATE parameter definitions and implications 6
2.2 Sensitivity analysis 8

3 Ammonia and Application Factors 11

3.1 Organism ammonia sensitivity 11
3.2 Ammonia toxicity identification evaluation 11
3.3 Application factors 11

4 Dredging Industry Input 15

5 Application of Findings: USACE Mobile District (SAM), Mobile Harbor Dredging 17

5.1 Introduction and Mobile ODMDS history 17
5.2 Mobile Harbor operations and maintenance (O&M) data and STFATE methodology 20
5.3 Original STFATE modeling parameters 20
5.4 Updated STFATE modeling parameters 23
5.5 Discussion 25
5.6 Conclusions 26

6 Conclusions and Recommendations 27

6.1 STFATE model analysis 27
6.2 Ammonia and application factors 28
6.3 Dredge industry input 28
6.4 Application of findings, SAM 28

References 30

Appendix A: STFATE Model Input Parameters for Optimization 32

Report Documentation Page

Figures and Tables

Figures

Figure 1. ODMDS within the overlapping USACE SAD and USEPA Region 4 jurisdictions. 3
Figure 2. USACE previously selected section 103 ODMDS (46 n.m.^{2})... 18
Figure 3. USEPA designated section 102 ODMDS (4.75 n.m.^{2})... 19

Tables

Table 1. Section 103 and STFATE input concerns identified by USACE Districts. 4
Table 2. STFATE parameters and units for typical section 102 and 103 applications. 6
Table 3.Mobile Bay 2011 O&M original and revised STFATE input parameters. 21
Table A-1. Grid spacing guidance. 35
Table A-2. Hopper dredge dimensions and characteristics. 41
Table A-3. STFATE coefficients with keyword and default value. 46

Preface

This study was conducted for the U.S. Army Corps of Engineers (USACE), South Atlantic Division (SAD). The technical monitor was Richard D. (Dylan) Davis, Navigation Program Manager, SAD, USACE, Atlanta, GA.

This report was prepared by Jase D. Ousley of the Coastal Engineering Branch (CEERD-HNC) of the Navigation Division (HN), Coastal and Hydraulics Laboratory (CHL); Dr. Paul R. Schroeder and Dr. Susan Bailey of the Environmental Engineering Branch (CEERD-EPE); Dr. Alan Kennedy of the Environmental Risk Assessment (CEERD-EPR) Branch of the Environmental Processes and Engineering Division, Environmental Laboratory (EL), U.S. Army Engineer Research and Development Center (ERDC); and Matthew J. Lang of the Mobile District (CESAM), U.S. Army Corps of Engineers. In addition to the authors, STFATE working group team members included Alan D. Shirey of the Charleston District (CESAC); John W. Bearce, Rebecca Lee-Duffell, and Joelle Verhagen of the Jacksonville District (CESAJ); Jennifer L. Jacobson and Nathan D. Lovelace (CESAM); Mary E. Richards of the Savannah District (SAS); and Douglas Piatkowski of the Wilmington District (SAW). At the time of publication, Tanya M. Beck was Chief, CEERD-HNC; Dr. Jackie S. Pettway was Chief, CEERD-HN; and W. Jeff Lillycrop was the Technical Director for Navigation, CEERD-HVT. The Deputy Director of CHL was Dr. Kevin Barry, and the Director was José E. Sánchez. Dr. Andy Martin was Chief, CEERD-EPE, and Buddy Goatcher was Chief, CEERD-EPR. The Deputy Director of EL was Dr. Jack Davis, and the Director was Dr. Beth Fleming.

COL Bryan S. Green was the Commander of ERDC, and Dr. Jeffery P. Holland was the Director.

1 Introduction

1.1 Background

The U.S. Army Corps of Engineers (USACE) Federal Navigation Program removes an average of 200 million cubic yards (Myd^3) of sediment from Federal navigational channels, waterways, ports, and harbors annually to maintain the nation's navigation system for commercial, national defense, and recreational purposes. From 1963–2013, reporting from the Navigational Data Center shows that 42% of the total volume of material dredged was placed in Ocean Dredged Material Disposal Sites (ODMDS) designated by the U.S. Environmental Protection Agency (USEPA). Regulation of dredged material placement within waters of the United States and ocean waters is a shared responsibility of USEPA and the USACE.

The Marine Protection, Research, and Sanctuaries Act (MPRSA, also called the Ocean Dumping Act) is the primary Federal environmental statute governing transportation of dredged material for the purpose of placement into ocean waters while Section 404 of the Clean Water Act (CWA) governs the discharge of dredged or fill material into "waters of the United States." Under the CWA and MPRSA, the USACE is the permitting authority for the proposed placement of dredged material. USACE governs the transportation of dredged material for the purpose of placing material into ocean waters. Permits for ocean placement of dredged material are subject to USEPA review and concurrence. Because the USACE cannot issue a permit to itself, the Code of Federal Regulations (CFR) 33, Parts 335 through 338, requires the USACE Civil Works program to abide by the same environmental regulations under the CWA Section 404 permits and are subject to USEPA review and 404(c) *veto* if USEPA's environmental guidelines are not met. USEPA has the lead for establishing the environmental guidelines/criteria that must be met to receive a permit under the CWA Section 404 and the MPRSA. USEPA is also responsible for designating recommended ocean placement sites for dredged material.

Section 102 of the MPRSA allows for dredged material proposed for ocean disposal to be placed in USEPA-designated ODMDSs. The USACE is required to use such sites for ocean placement to the extent feasible. USEPA's ocean dumping regulations in 40 CFR Part 228 provides criteria and procedures for the designation and management of ocean placement

sites and lists the currently designated sites by USEPA region. The USACE is also authorized to select sites for ocean placement under Section 103 of the MPRSA, with USEPA concurrence, if use of an USEPA-designated site is not feasible (http://water.EPA.gov/type/oceb/oceandumping/dredgedmaterial.oceansites.cfm).

The Short-Term FATE of dredged material placed in open water (STFATE) model was created by the U.S. Army Engineer Research and Development Center (ERDC) and is used to assist with MPRSA Section 103 processes with the USEPA. STFATE enables the computation of the physical fate of dredged material disposed in open water and simulates the movement of the disposed material as it falls through a water column, spreads over the bottom, and is transported and diffused as suspended sediment by the ambient current. From 2012–2015, an increasing number of STFATE results from specific USACE South Atlantic Division (SAD) projects resulted in costly load limitations (bin restrictions) on the amount a hopper dredge or scow may be loaded, tide and current placement restrictions, restricted release zones, and other placement constraints. As a result, the USACE SAD regional navigation manager stood up an internal USACE technical working group to assess, resolve, and minimize unwarranted MPRSA Section 103 limitations.

This report documents the findings and recommendations of the SAD STFATE working group.

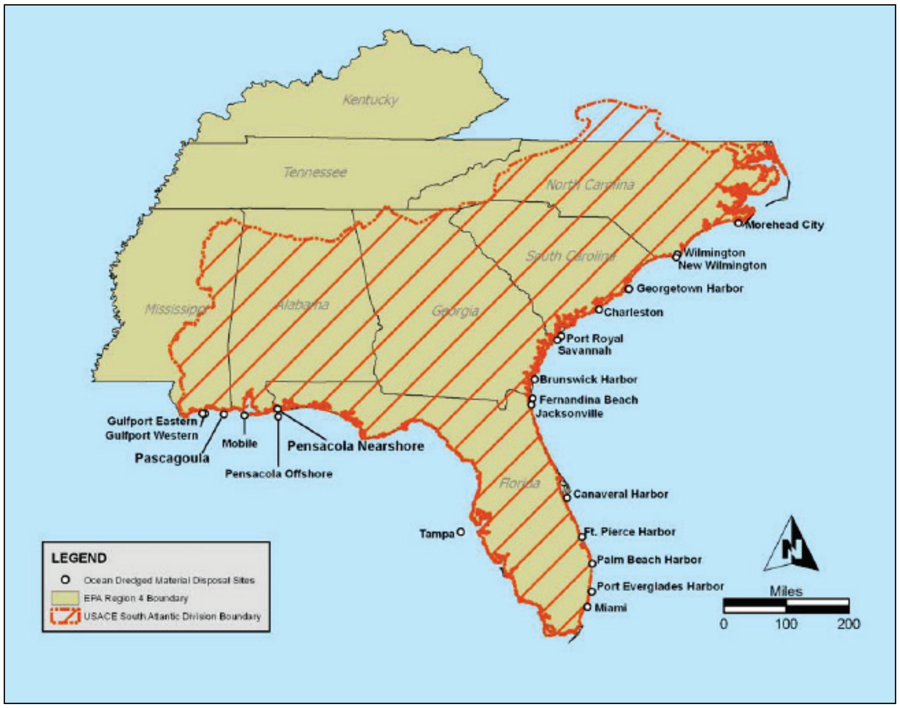
1.2 Ocean Dredged Material Disposal Sites (ODMDS)

The study area consists of the USACE SAD Districts Wilmington (SAW), Charleston (SAC), Savannah (SAS), Jacksonville (SAJ), and Mobile (SAM) within the jurisdiction of USEPA Region 4. This study area contains 22 ODMDSs (Figure 1). However, the findings presented in this report can directly be applied to any action employing STFATE modeling for ocean placement permitted under MPRSA Section 102 or Section 103 regulation.

1.3 Baseline information

The SAD STFATE technical working group, henceforth called “the working group,” was initiated in 2013. At that time, there appeared to be confusion and uncertainty regarding the STFATE model input parameters and their relationship to specific operational restrictions.

Figure 1. ODMDS within the overlapping USACE SAD and USEPA Region 4 jurisdictions.



From an operations perspective, there is an underlying cost concern with bin restrictions and other imposed constraints associated with the model outputs warranting a more refined evaluation of STFATE parameters. It is important that model results are based on a clear reflection of the project-specific operating conditions and that this is clearly articulated to USEPA.

The working group identified the need for consistency in applying STFATE across the Districts, a standard approach for evaluating *mixing*, and a re-evaluation of the STFATE model. STFATE model input parameters, including those that are fixed and flexible, needed to be assessed with the range of variability around each parameter to determine the inputs that are unnecessarily restrictive. Additionally, the working group identified the need to better communicate the *reality* of dredging operations and do what is appropriate to assure that STFATE input parameters reflect the project environment and the standard operating procedures of dredging contractors. Table 1 presents issues and concerns with STFATE inputs as stated by SAD Districts. Input from Charleston District (SAC) was not available at the time of publication.

Table 1. Section 103 and STFATE input concerns identified by USACE Districts.

District	Category	Issue/Concern	Comment	Impact	Recommendation
SAW	Ammonia	(1) Poorly implemented bioassay resulting in skewed LC50.	(1) Without appropriate acclimation of bioassays, LC50 may be misreported.	(1) STFATE model outputs can be skewed based on incorrect inputs.	Prepare improved bioassay guidance/ SOW recommending elimination of inappropriate species and ammonia drivers.
SAS	Ammonia	(1) Species selection and sensitivity in 103 evaluations.	(1) SAS utilized sea urchins (Arbacia punctulata) (a species not even present in the project area) in recent 103 evaluation for Brunswick Harbor, which were overly sensitive to ammonia.	(1) Bin restrictions ranging from 5,500 to 9,500 yd3. Elimination of existing and future large capacity hopper dredges.	Prepare improved bioassay guidance/SOW recommending elimination of inappropriate species and ammonia drivers.
	Operational	(2) Site-specific data input for the model.	(2) In the absence of site-specific data, offshore surrogate buoy data was used to reflect representative current input parameters for the ODMDS.	(2) Actual modeled currents within the ODMDS were significantly different from the predicted currents resulting in skewed model outputs and potential unnecessary constraints.	Conduct velocity and density profiles at actual sites where appropriate. Require necessary operational controls in contracts (e.g., Mayport) relative to appropriate offsets. Conduct a sensitivity analysis to access the range of velocities impacting placement.
SAJ	Operational	(1) Ground truth plumes.	(1) There are new methodologies to better ground truth plumes.	(1) Current coefficients may be overly conservative.	It was suggested that this would entail a significant field effort and may not show much change from the original coefficients. The working group agreed that this effort should not be pursued in the short term.
		(2) Site-specific operating parameters.	(2) STFATE model outputs do not reflect actual site-specific operating parameters.	(2) Currently do not take advantage of offset opportunities relative to real-time, site-specific conditions.	Conduct site-specific management of operations to address discharge relative to real-time operating conditions (currents tide cycles, etc.). Evaluate DQM data for example project (e.g., Mayport) coupled with Industry input to better understand actual operating parameters relative to different plant type.

District	Category	Issue/Concern	Comment	Impact	Recommendation
SAM	Ammonia	(1) Ammonia concentrations and application factors (consistent with SAW and SAS issues).	(1) Allow aging time for sample in attempt to strip ammonia before running bioassay tests.	(1) STFATE model outputs can be skewed based on incorrect inputs.	Prepare improved bioassay guidance/SOW recommending elimination of inappropriate species and ammonia drivers.
SAW	Ammonia	(1) Poorly implemented bioassay resulting in skewed LC50.	(1) Without appropriate acclimation of bioassays, LC50 may be misreported.	(1) STFATE model outputs can be skewed based on incorrect inputs.	Prepare improved bioassay guidance/SOW recommending elimination of inappropriate species and ammonia drivers.

NOTES:

SAJ: Jacksonville District, SAM: Mobile District, SAS: Savannah District, SAW: Wilmington District. SOW: Scope of Work

For more background on the topics covered in this report, reference the *Evaluation of Material Proposed for Discharge to Waters of the US – Inland Testing* (USEPA 1998) and the *Regional Implementation Manual - Requirements and Procedures for Evaluation of the Ocean Disposal of Dredged Material in Southeastern U.S. Atlantic and Gulf Coast Waters (**SERIM**)* (USEPA/USACE 2008).

1.4 Objectives

The working group's objective was to develop an applied understanding of STFATE implementation and optimize efficiencies as an output of the STFATE model.

This report of findings is divided into five major sections:

- The STFATE Model Analysis
- Ammonia
- Dredge Industry Input
- Application of Findings: SAM
- Conclusions and Recommendations.

2 STFATE Model Analysis

2.1 STFATE parameter definitions and implications

The STFATE model simulates the movement of dredged material from an instantaneous discharge as it falls through the water column, spreads over the bottom, and is transported and diffused as a plume by the ambient current. Short-term fate of dredged material disposed in open water is an integral part of assessing water-column environmental impacts. The model can provide an estimate of concentrations in the receiving water as well as the initial deposition pattern of material on the bottom. Estimates of water column concentrations are often needed to determine mixing zones. The initial deposition pattern of material on the bottom is required in long-term sediment transport studies that assess the potential for erosion, transport, and subsequent sedimentation of the material.

Input data for STFATE are grouped into the following general areas: site data, velocity data, material data, operations data, execution data, and coefficients (Table 2). Appendix A contains detailed information on the optimization of STFATE model input parameters.

Table 2. STFATE parameters and units for typical section 102 and 103 applications.

PARAMETER	Units	
Site Description		
Number of grid points (L-R, +z-direction)		
Number of grid points (T-B, +x-direction)		
Grid spacing (left to right) z-axis	feet	ft
Grid spacing (top to bottom) x-axis	feet	ft
Constant water depth	feet	ft
Bottom roughness	feet	ft
Bottom slope (x-direction)	degrees	deg
Bottom slope (z-direction)	degrees	deg
Depth	feet	ft
Salinity	parts per thousand	ppt
Temperature	Celsius	C
Density	grams per cubic centimeter	g/cc
Ambient Velocity		
Average velocity at a location of average depth	feet per second	fps

PARAMETER Site Description	Units	
Placement Operation		
Placement point top of grid (x-axis)	feet	ft
Placement point left edge of grid (z-axis)	feet	ft
Location of placement site		
Upper left corner distance from top edge (x)	feet	ft
Upper left corner distance from left edge (z)	feet	ft
Lower right corner distance from top edge (x)	feet	ft
Lower right corner distance from left edge (z)	feet	ft
Length of vessel bin	feet	ft
Width of vessel bin	feet	ft
Distance between bins	feet	ft
Preplacement draft	feet	ft
Postplacement draft	feet	ft
Time to empty vessel	seconds	sec
Number of bins that open simultaneously		
Number of discrete openings of sets of bins		
Vessel velocity in x-direction	feet per second	ft/sec
Vessel velocity in z-direction	feet per second	ft/sec
Number of layers		
Volume of each layer	cubic yards	yd^3
Model Default Coefficients		
Settling coefficient (BETA)		
Apparent mass coefficient (CM)		
Drag coefficient (CD)		
Form drag collapse cloud (CDRAG)		
Skin friction collapse cloud (CFRIC)		
Drag ellipse wedge (CD3)		
Drag plate (CD4)		
Friction between cloud and bottom (FRICTN)		
4/3 Law horizontal diffusion coefficient (ALAMDA)		
Unstratified vertical diffusion coefficient (AKYO)		
Cloud/ambient density gradient ratio (GAMA)		
Turbulent thermal entrainment (ALPHAO)		
Entrainment collapse (ALPHAC)		
Stripping factor (CSTRIP)		

PARAMETER	Units	
Site Description		
Input, Execution, and Output Keys		
Duration of simulation	seconds	sec
Long-term time-step	seconds	sec
Convective descent output		
Collapse phase output option		
Number of print times for diffusion		
Number of depths for output		
Depths for output	feet	ft
Water Quality - Tier II		
Location of dredge material		
Contaminant		
Predicted initial concentration in fluid	micrograms per liter	ug/L
Acute water-quality criteria at edge of mixing zone	micrograms per liter	ug/L
Chronic water-quality criteria at edge of mixing zone	micrograms per liter	ug/L
Background concentration	micrograms per liter	ug/L
Material properties		
Class volumes		
Toxicity - Tier III		
Acute toxicity concentration (LC50, EC50, LOEC)	percent	%
LPC*	percent	%
Dilution required	percent	%

*Where LPC is the *limiting permissible concentration*, determined as a no-effect concentration or by an acutely toxic concentration multiplied by an application factor.

Default settings for STFATE parameters that are most commonly accepted by USEPA are the midrange values for each parameter.

2.2 Sensitivity analysis

The STFATE model requires user input for a number of parameters related to the placement operation, placement site characteristics, dredged material characteristics, evaluation objectives, and model coefficients. One use of the model is to evaluate the impacts of changing various operational parameters. However, some parameters may have significant impacts whereas others have little effect. A sensitivity analysis was performed to show which parameters can be altered to effectively impact resulting

concentrations. Furthermore, collection of necessary data to run STFATE can be tedious. The sensitivity analysis demonstrated the degree of accuracy needed to run the model (i.e., which parameters require input with a high degree of accuracy and which can be more loosely estimated). The STFATE sensitivity analysis investigated the following parameters:

- current velocity
- current velocity assumption of log profile
- dredging vessel velocity and heading
- time to discharge and number of discharges
- grid cell size
- coefficient ALAMDA
- Pritchard expression to calculate Vertical Diffusion Coefficient (AKY0)
- long-term time-step
- water depth
- barge/hopper size
- barge/hopper dimensions
- density gradient
- dredging-site water salinity.

A series of barge and hopper discharge simulations were performed using STFATE, varying a number of input parameters to determine the sensitivity and impacts on both modeling and operations. From this series of simulations, the following information can be concluded. **Bold** parameters below were deemed to have significant model impacts.

1. Parameters that appear to have little impact on results include assumption of log profile for current velocity, time to discharge, Pritchard expression to calculate Vertical Diffusion Coefficient (AKY0), long-term time-step, and salinity/density of the dredging site water.
2. **Grid cell size can effect concentrations by at least an order of magnitude.** It is important to analyze resulting concentration curves to ensure the results are realistic, generating a smooth concentration drop rather than erratic behavior. In general, one should use the smallest grid size the model will allow (based on limitations of the number of grid cells). Sometimes it may be necessary to use a larger grid cell for results at later time-steps and smaller cell sizes for earlier times.
3. **The velocity and heading of the dredging vessel during discharge may impact concentrations in some instances.** Spreading by releasing the material slowly while the vessel is in motion

appears to decrease concentrations, with greater reduction where current velocity is low. Discharge while traveling against or transverse to the current has similar impacts while traveling with the current was less effective and may actually increase concentrations. The direction of water flow, water velocity, and movement of placement location within the site makes a difference in output values. This input requires accurate/up-to-date data for current and velocity, which is not always available (user issue). The current and velocity input is applying a snapshot in time for these parameters and applying them across a wide range of seasonal and temporal changes that may not adequately represent the actual environment the model is trying to characterize.

4. **The coefficient ALAMDA has a dramatic impact.** ALAMDA is addressed in Section 3.
5. Discharge in deeper water results in lower concentrations than in shallow depths. Similarly, plumes passing through deeper water experience greater dilution.
6. **Varying the density gradient can have a severe effect on concentrations.** However, simulated impacts of changing density did not behave in a predictable or realistic manner. Until the model can be made more accurate, it is recommended a constant density profile be applied except where significant stratification occurs (a difference greater than 0.001 kg/L over a 10 m distance).
7. While current velocity does not have a large effect on concentrations, the velocity does impact the location of the plume and time to reach site boundaries. In general, the plume centroid travels approximately the same speed as the current velocity.
8. Reducing the volume of water released reduces the mass of contaminants and in turn reduces concentrations. Reducing the contaminant mass release can be accomplished by (1) reducing the volume of material discharged, (2) altering dredging operations to entrain less water (e.g., using a clamshell rather than a hopper), or by (3) reducing the fraction water such as in overflow operations. However, the reduction in concentration is not necessarily proportional to the reduction in volume (e.g., for the test case, a 50% reduction in volume yielded only 25% to 40% reduction in concentration).
9. The dimensions of the barge or hopper have minimal effect on concentrations, allowing the user to input approximate dimensions. Opening multiple sets of bins with the vessel traveling during discharge can be used to spread the plumes and dilute concentrations. The preplacement draft may also affect resulting concentrations.

3 Ammonia and Application Factors

3.1 Organism ammonia sensitivity

Currently, organism sensitivity to ammonia concentration is not addressed in guidance documents. The Southeast Regional Implementation Manual (SERIM) needs to undergo revision to include a table of ammonia reference toxicant concentrations indicating organism sensitivity to ammonia. Additional relevant ammonia toxicity information is provided in Kennedy et al. (2015).

3.2 Ammonia toxicity identification evaluation

SERIM Appendix H has an ammonia amelioration procedure for solid phase and suggested (unofficial) methods for reducing ammonia concentrations in elutriate toxicity tests in the form of a white paper. However, technical issues with the approach were identified in this effort, and the text erroneously implies that ERDC concurs with the methods described in the current version of the SERIM (USEPA/USACE 2008).

The SERIM modification will include a revised procedure for suspended phase ammonia reduction for ammonia toxicity reduction evaluation (TRE). The ammonia amelioration appendix will be revised extensively, and methods for identifying and isolating ammonia impacts in the elutriate toxicity tests utilized in the water column evaluation will be technically improved in the new Appendix N of the updated SERIM (Kennedy et al., in preparation [a]). Further, an overview of elutriate TRE methods will be added to the main body of the updated SERIM.

3.3 Application factors

Application factors (AF) have historically been applied to acute toxicity test data, specifically lethal concentrations causing 50% mortality (LC50), to extrapolate a safe concentration for continuous long-term (chronic) exposure. The 40 CFR 227 adapted this approach for the acute toxicity tests employed in elutriate (water column impact) testing without consideration to the short-term discharge and exposure at the dredged material placement site that occurs with certain dredging and placement methods. Thus, the approach in the 40 CFR 227.27 establishes in many cases an over-protective limiting permissible concentration (LPC) by

applying an AF intended for chronic protection to acute toxicity test results. The 40 CFR 227.27 suggests a default AF of 0.01 but also states a different AF can be applied if scientifically defensible:

> 40 CFR 227.27(1)(2) That concentration of waste or dredged material in the receiving water which, after allowance for initial mixing, as specified in §227.29, will not exceed a toxicity threshold defined as 0.01 of a concentration shown to be acutely toxic to appropriate sensitive marine organisms in a bioassay carried out in accordance with approved USEPA procedures.
>
> 40 CFR 227.27(a)(3) When there is reasonable scientific evidence on a specific waste material to justify the use of an application factor other than 0.01 as specified in paragraph (a)(2) of this section, such alternative application factor shall be used in calculating the LPC.

Thus, the current version of the SERIM (USEPA/USACE 2008) lists a 0.01 AF and is overly restrictive; the updated version will be improved to include consideration of alternative AFs. In cases where there are strong lines of evidence suggesting that specific chemicals or analytes are the likely cause of toxicity, efforts should be made to determine and/or apply a more specific, technically defensible AF.

Ammonia is naturally present in the interstitial water of sediment and is consequently a common contaminant causing mortality in elutriate toxicity tests. It is generally agreed that ammonia is a nonpersistent contaminant (NAS 1972) that is much less of a concern than persistent contaminants such as metals. USEPA and USACE have agreed that ammonia is not a contaminant of concern in benthic sediments (USEPA 1994; USEPA/USACE 1998). It is also documented that alternative AFs are more appropriate for discharges of nonpersistent contaminants such as ammonia in the water column (NAS 1972):

> For persistent (half-life in water > 8 weeks) and non-persistent (half-life in water < 8 weeks) chemicals, application factors of 0.01 and 0.05 are recommended, respectively.

> For ammonia and certain other pollutants, levels below 0.1 of the lethal concentration do not seem to contribute to the lethal action of a mixture.
>
> Concentration of materials that are non-persistent or have noncumulative effects should not exceed 0.1 of the 96-hour LC50 at any time or place after mixing with the receiving waters. The 24-hour average of the concentration of these materials should not exceed 0.05 of the LC50 after mixing.

There is literature evidence (Thurston et al. 1983, 1986; Hazel et al. 1982; Miller et al. 1990; Boardman et al. 2004; Batley and Simpson 2009) suggesting higher AFs are more appropriate for ammonia (Kennedy et al. 2015). Using conventional chronic endpoint indices, Thurston and co-workers estimate an acute-to-chronic ration (ACR) for ammonia of 9.3 (AF = 0.11). Generally, nonpersistent chemicals such as ammonia have relevant AFs of 0.05 to 0.10 (Hazel 1982). In addition, there are general ammonia ACRs (AF = 0.05 to 0.2) and ACRs specific for *Menidia* fish (AF = 0.05) and *Americamysis* shrimp (AF = 0.14) that can be obtained from the literature and converted to AFs (Miller et al. 1990; Boardman et al. 2004; Batley and Simpson 2009). Therefore, with consideration to 40 CFR 227.27(a)(3), NAS (1972), and the cited literature, when ammonia is the sole cause for toxicity in elutriate bioassays, it is appropriate to apply an alternative AF to acute toxicity data to establish the LPC. A more detailed discussion of these issues and alternative AFs is provided in Kennedy et al. (2015). USEPA, Region 4, currently approves use of an alternate AF of 0.05 for all assays (regardless of whether the endpoint is survival or development) when ammonia toxicity is identified and when it is shown that ammonia is the sole cause of toxicity in the suspended phase assay.

An additional conclusion of this effort is that the 0.05 AF is likely inappropriate (overly protective) for the 48-hour elutriate embryo development assay. The AF approach was originally intended for larval fish and invertebrate acute survival tests that result in LC50 values. However, the same approach has been recently applied to embryonic development toxicity tests using mollusks and echinoderms that result in an effective concentration (EC50) value. The Ocean Testing Manual (USEPA 1991) never mentions applying AFs to an EC50 value. Further, USEPA/USACE (1998) clearly states that it is recognized that "…the 0.01 factor is intended for acute mortality data (e.g., relating acute to chronic toxicity) and not for

more subtle effects such as abnormalities, growth or reproduction, including EC50 data." Ammonia in elutriates results in extremely low EC50 values in larval development assays, ultimately contributing to dredged material placement volume restrictions and additional dredging costs for USACE. The sensitivity of this type of bioassay to ammonia is more than 15 times greater than the 96-hour survival tests (Kennedy et al. 2015). Therefore, the recommendation is that the no-observed-effect concentration (NOEC) generated during bioassays be adopted as the LPC for embryonic development bioassays (Batley and Simpson 2009; Clarke et al. 2002). ERDC (Kennedy et al., in preparation [b]) is currently providing technical evidence that this approach is protective of chronic exposure establishing a development-test-specific AF in order to comply with the language in 40 CFR 227.27.

4 Dredging Industry Input

Technical meetings were held on 18, 19 February 2015 at the USACE SAD headquarters in Atlanta, GA. Attendees included USACE representatives from SAD Headquarters, Districts and the ERDC, dredging industry representatives, and the USEPA. During this meeting, early findings from the STFATE sensitivity analysis were presented for discussion.

As industry has introduced new and larger dredges into the fleet, the USACE faces increased pressure to meet existing environmental criteria. During recent dredging contracts in the Southeast and Gulf Coast regions of the country, regulating agencies have imposed load size restrictions for hopper dredges and/or dump scows using an ODMDS for placement of dredged material due to STFATE modeling results. The USACE recognizes that load size restrictions are counterproductive for maximizing the industry's increasing dredge efficiencies and cost effectiveness.

In general, dredging industry representatives stated that operational constraints are preferred over load restrictions. The USACE sought input from the dredging industry regarding operational changes that could be made with respect to where and how material is placed within an ODMDS to reduce or eliminate the need for load size restrictions. Also, the USACE sought input on how dredgers could control the release of potentially containing contaminants of concern during dredged material placement.

Operational controls include actions such as

- adjusting the length of time used to dump a scow or hopper dredge
- partially opening bins or split hull for slower release and spreading of dredged material
- altering vessel speed through the water during placement (maximum and minimum)
- adjusting vessel heading during placement relative to the water current direction
- varying bin discharge operations and options (number of bins, location of bins, sequence)
- increasing/decreasing the overflow in scows and hoppers

- adjusting the percentage of entrained water in scows (with or without overflow)
- using separate ODMDS release zones according to tide tables.

Implementation of operational controls has been beneficial at SAJ. As an alternative to load limitations, SAJ has used smaller release zones within the ODMDS relative to the direction of the current to allow a greater mixing area. Industry was instrumental in providing important information that facilitated this path forward. Further, operational management expectations must be clearly communicated to the contractor and implementation of controls must be transparent to avoid enforcement actions from regulating agencies. Dredging industry representatives requested that USACE include them as early as possible during project development when sediment contaminants are a concern. Additionally, they recommended that USACE work with ports and naval stations to proactively address sources of contamination before contaminants are discharged into dredging areas.

5 Application of Findings: USACE Mobile District (SAM), Mobile Harbor Dredging

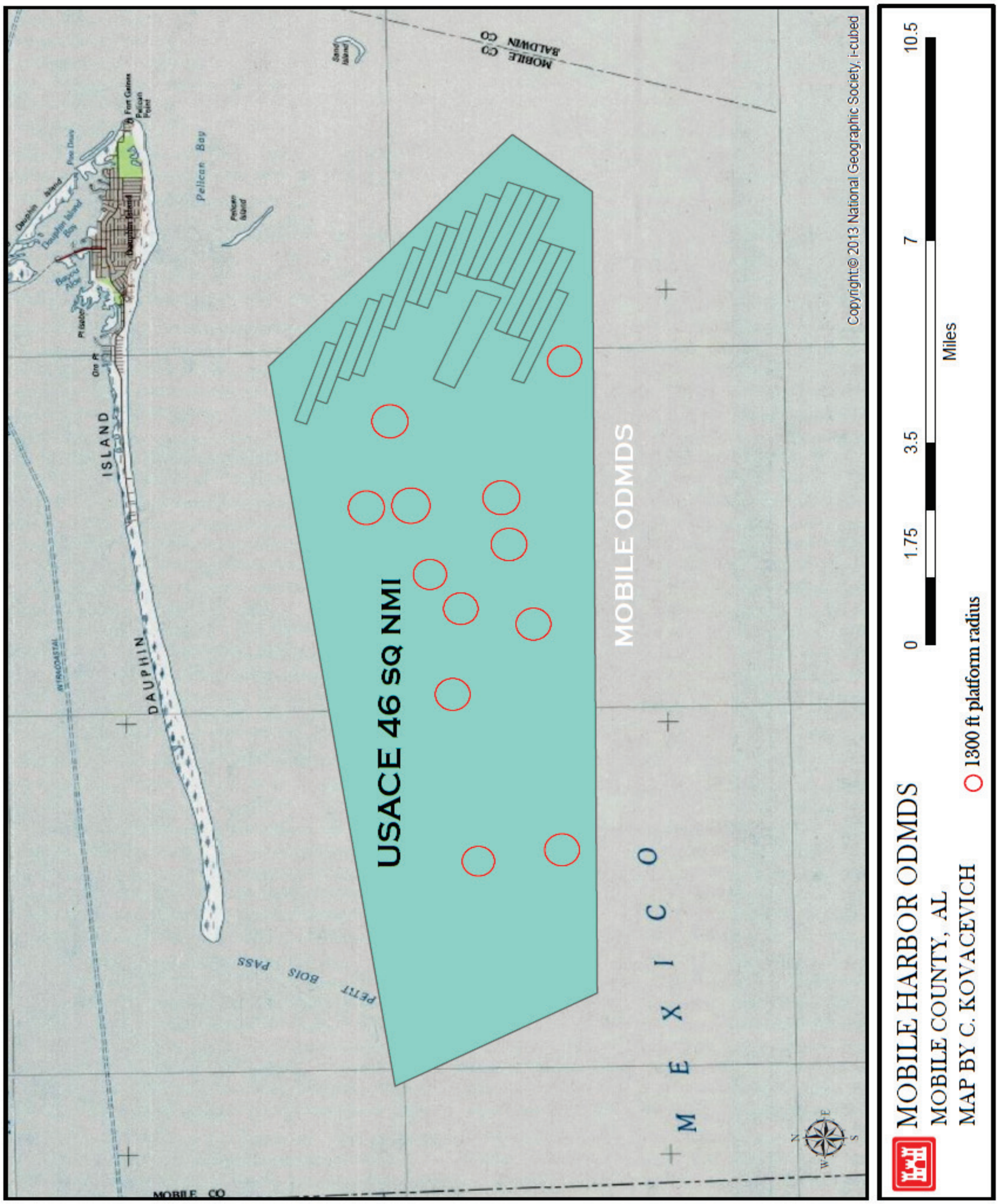
5.1 Introduction and Mobile ODMDS history

The historically used Mobile ODMDS was established under MPRSA Section 103(b)(3) in 1985, located south of Dauphin Island, AL, and was approximately 46 square nautical miles (n.m.^{2}) (Figure 2). This Section 103 ODMDS carried a 5-year life with the possibility of a one-time, 5-year extension. In 1986, USEPA formally designated an MPRSA Section 102(c) ODMDS approximately 4.75 n.m.^{2} (

) in the area, located in the southwest corner of the previously selected USACE Section 103(b)(3) Mobile ODMDS. Efforts undertaken to expand and designate the larger, previously selected, 46 n.m.^{2} ODMDS began approximately the year 2000. Currently, a smaller 19 n.m.^{2} ODMDS is being pursued for designation under MPRSA Section 102(c).

Historical STFATE modeling for inclusion in a Section 103 evaluation for suitability of material for ocean placement was reassessed given an updated Site Management and Monitoring Plan (SMMP) for the 4.75 n.m.^{2} ODMDS (USEPA/USACE 2015). Conservatism of technical modeling parameters led to greatly restricted placement volumes. Past model results indicated ocean placement limitations of approximately 3,500 and 4,000 yd^3 for Mobile River and Bay sediments, respectively. From an economic perspective, this magnitude of restriction (Mobile Harbor typically uses hoppers capable of placing between 5,000 to 20,000 yd^3 per load) could potentially increase annual costs upwards of $19M leading to an approximate 50% reduction in operational efficiency. These factors illustrate the need for critical, and in-depth, analysis of how past STFATE modeling resulted in these restrictions. Questions arose as to which input parameters USACE could change while maintaining compliance with MPRSA and USEPA ocean dumping regulations.

Figure 2. USACE previously selected section 103 ODMDS (46 n.m.^{2}).



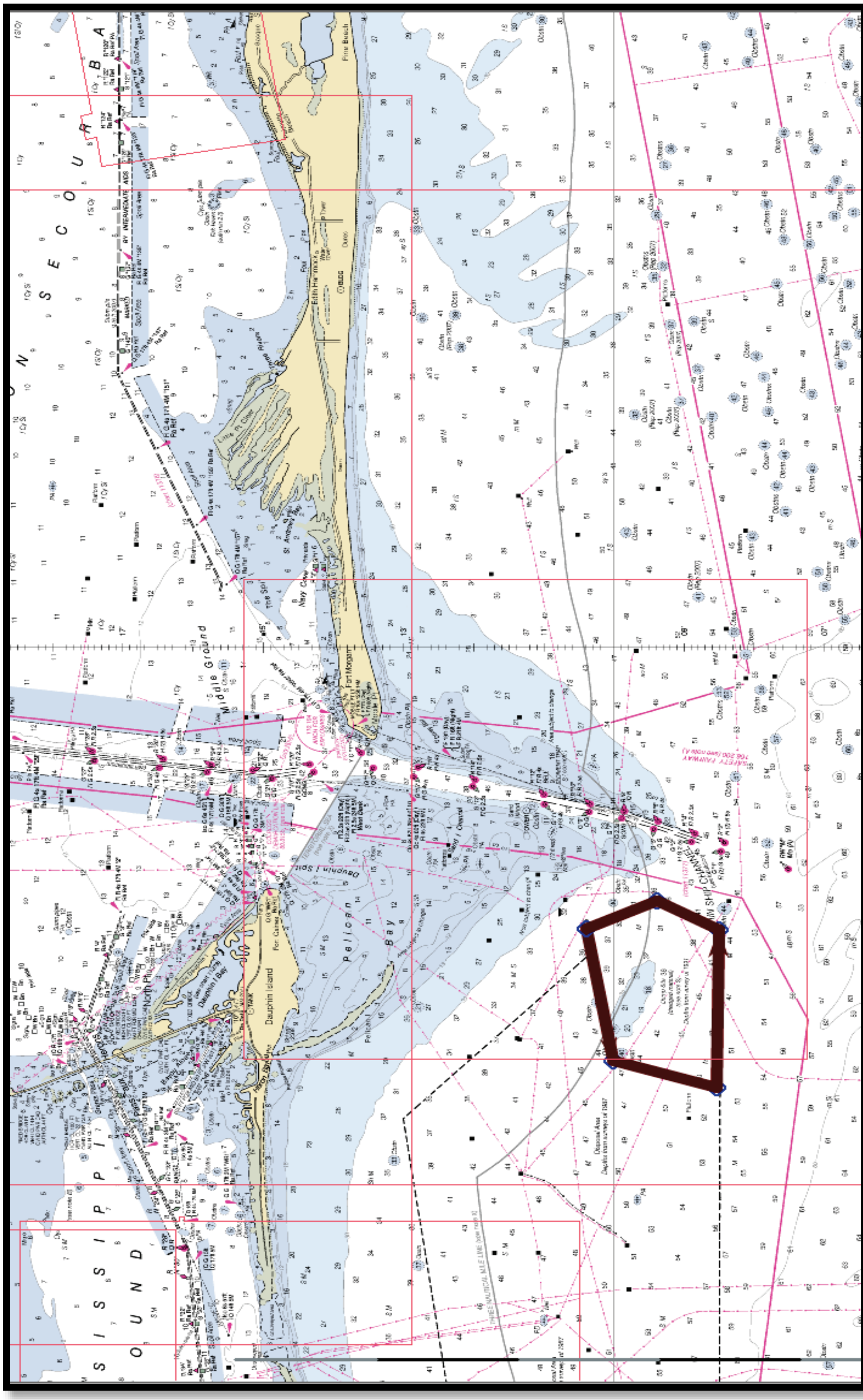


Figure 3. USEPA designated section 102 ODMDS (4.75 n.m.^{2}).

5.2 Mobile Harbor operations and maintenance (O&M) data and STFATE methodology

Representative data from Mobile O&M dredged material for ocean placement was selected for this analysis due to specific project importance from a SAM perspective with regard to optimized operational and environmental conditions. Data were compiled in 2010 for ocean placement suitability and subsequent compliance with USEPA ocean dumping regulations and MPRSA guidelines. Data were analyzed utilizing standard STFATE model input parameters listed in the SERIM (USEPA/USACE 2008) and default model coefficients. Use of standard input parameters focused on outdated data for conditions of environmental influence (velocity and current direction) and operational conditions (vessel size and velocity within the placement site). The USACE further investigated these issues due to prior model limitations causing restrictions to environmental and operational viability. Through these investigations, USACE determined a number of standard input parameters requiring updates. Initially, parameters associated with grid resolution and ambient velocity and direction (both environmental and operational) were analyzed for a more representative model output.

5.3 Original STFATE modeling parameters

Table 3 illustrates original STFATE modeling input parameters utilized for the 2010 Mobile Harbor O&M data set for placement at the Mobile ODMDS. Quantitative analysis of representative subject data resulted in substantial placement vessel restrictions (3,500 yd^3) based on conservative values from the 2008 SERIM. Grid resolution, ambient velocity, placement location within the site, and vessel characteristics were reassessed. Original ambient velocity identified by Hoffer (1984) was expressed as -0.984 ft/sec in the z-direction (east to west) with a velocity of 0.0 ft/sec in the x-direction (north to south) at a depth of 23 ft. Dredged material placement in the modeling process considers the center of the defined grid as the default location. However, coordination with USEPA allows the placement location to be moved based on environmental conditions. Originally, each load was placed at 4,800 ft on the x-axis (north-south) and 10,000 ft on the z-axis (east-west) to account for ambient velocity conditions. This location was selected in relation to the center of the site from a north-south orientation and to the east of center to account for ambient velocity model inputs in the westerly direction. Along with ambient velocity and placement location, vessel characteristics and operations factor greatly in model outputs.

Original vessel parameters described entire vessel length (390 ft) and width (78 ft) instead of bin length and width. Vessel draft, number of bins, and time to empty dredging vessels also needing updates resulted in extreme overconservatism of modeling results.

Table 3.Mobile Bay 2011 O&M original and revised STFATE input parameters.

Parameter			
Site Description	Units	*Original Input Value	**Revised Input Value
Number of grid points (L-R, +z direction)		96	80
Number of grid points (T-B, +x direction)		96	80
Grid spacing (left to right) z-axis	ft	150	250
Grid spacing (top to bottom) x-axis	ft	100	250
Constant water depth	ft	46	46
Bottom roughness	ft	0.005	0.005
Bottom slope (x-direction)	deg	0	0
Bottom slope (z-direction)	deg	0	0
Salinity *@ 0 ft	ppt	15	
*@ 46 ft	ppt	33	
Temperature *@ 0 ft	C	27	
*@ 46 ft	C	20	
Density **0 ft	g/cc	1.0082	1.0206
**26 ft	g/cc	1.0236	1.0206
**46 ft	g/cc		1.0207
Ambient Velocity		depth averaged	2-point at constant depth
Depth *23 ft, **11 ft	fps	x-direction 0.000	x-direction 0.12
*23 ft, ** 11 ft	fps	z-direction -0.984	z-direction -0.41
** 33 ft	fps		x-direction 0.22
** 33 ft	fps		z-direction -0.37
Placement Operation			
Placement point top of grid (x-axis)	ft	4,800	6,000
Placement point left edge of grid (z-axis)	ft	10,000	15,000
Placement over depression		No	No
Bottom depression length x-direction	ft	0	0
Bottom depression length z-direction	ft	0	0
Bottom depression average depth	ft	0	0
Location of placement site			
Upper left corner distance from top edge (x)	ft	100	5,455
Upper left corner distance from left edge (z)	ft	150	3,414

Parameter			
Site Description	Units	*Original Input Value	**Revised Input Value
Lower right corner distance from top edge (x)	ft	9,400	14,545
Lower right corner distance from left edge (z)	ft	14,100	16,586
Length of vessel bin	ft	309	158
Width of vessel bin	ft	78	70
Distance between bins	ft	5	0
Preplacement draft	ft	20	35
Postplacement draft	ft	10	17
Time to empty vessel	sec	90	45
Number of bins that open simultaneously		1	1
Number of discrete openings of sets of bins		11	1
Vessel velocity in x-direction	ft/sec	1.7	4.2
Vessel velocity in z-direction	ft/sec	0	4.2
Number of layers		1	1
Volume of each layer	yd^3	4,000	20,000
Model Default Coefficients			
Settling coefficient (BETA)		0	0
Apparent mass coefficient (CM)		1	1
Drag coefficient (CD)		0.5	0.5
Form drag collapse cloud (CDRAG)		1	1
Skin friction collapse cloud (CFRIC)		0.01	0.01
Drag ellipse wedge (CD3)		0.1	0.1
Drag plate (CD4)		1	1
Friction between cloud and bottom (FRICTN)		0.01	0.01
4/3 Law horizontal diffusion coefficient (ALAMDA)		0.001	0.001
Unstratified vertical diffusion coefficient (AKYO)		0.025	0.025
Cloud/ambient density gradient ratio (GAMA)		0.25	0.25
Turbulent thermal entrainment (ALPHAO)		0.235	0.235
Entrainment collapse (ALPHAC)		0.1	0.1
Stripping factor (CSTRIP)		0.003	0.003
Input, Execution, and Output Keys			
Duration of simulation	sec	14,400	14,400
Long-term time-step	sec	600	600
Convective descent output			
Collapse phase output option			
Number of print times for diffusion			

Parameter	Units	*Original Input Value		**Revised Input Value	
Site Description					
Number of depths for output		4		4	
Depths for output	ft	0, 15, 30, 45		0, 15, 30, 45	
Water Quality - Tier II					
Location of dredge material		Mobile River		Mobile River	
Contaminant		Lindane (Gamma-BHC)		Lindane (Gamma-BHC)	
Predicted initial concentration in fluid	ug/L	0.66		0.66	
Acute water quality criteria at edge of mixing zone	ug/L	0.16		0.16	
Chronic water quality criteria at edge of mixing zone	ug/L				
Background concentration	ug/L	0		0	
Toxicity - Tier III		Average	Lowest	Average	Lowest
EC50	%	50.1	23	50.1	23
0.01 EC50	%	0.501	0.23	0.501	0.23
Dilution required	%	200	435	200	435

5.4 Updated STFATE modeling parameters

Through internal and interagency discussions between USEPA and USACE and sensitivity analyses, Table 3 lists input parameters altered for inclusion in future project considerations. Differences between the original and revised STFATE modeling parameters focus on grid resolution, density at varying depth profiles, placement operation parameters, and ambient velocities at varying depths and directional orientations. Alterations in grid resolution produced marginal improvement when analyzed individually. Grid resolution, coupled with all other parameters, showed a marked decrease in load restrictions on the order of tripling outputs to approximately 10,500 yd^3 (compared to the original 3,500 yd^3). To achieve this decrease in restriction, ambient velocity data and placement location were updated to reflect optimized conditions. Velocity data were collected as presented in *Final Report – Mobile ODMDS Designation Survey, Mobile, AL* (USEPA 2010). Revised values illustrate changes to ambient velocity at depths of 11 and 33 ft compared to original depth data at a single point of 23 ft.

Subsequent alterations to operational controls, such as bin dimensions, number of bins, bin emptying times, and vessel velocity and direction, provide further relief from previously quantified scow limitations. Vessel characteristics for this current analysis were modeled with parameters

attributed to the dredge *Stuyvesant*. The *Stuyvesant* is representative of the typical range of vessel used for Mobile Harbor O&M dredging. Comparisons of original and revised input parameters illustrate a marked decrease in length, width, and time to empty the vessel between original quantification and current analyses.

The single factor, as discussed previously in Section 3, having the greatest influence on modeling results was the implementation of an alternate AF regarding larval development (EC50). Typically, an AF of 0.01 (40 CFR 227.27(1)(2)) was analyzed against larval development to determine an EC50 endpoint. As discussed in Section 3, while development tests are considered acute, they are unlike acute lethality tests (LC50) in that they generate an embryonic development endpoint during the most sensitive life stage (ASTM International 2012a,b). Thus, technical relevance of applying the regulatory default 0.01 AF to an embryonic development endpoint is questionable since EC50 is fundamentally different than LC50 endpoints (USEPA/USACE 1998) (40 CFR 227.27(a)(3)) (Kennedy et al. 2015).

This ERDC Technical Report states ammonia as being the primary constituent of concern associated with alternate AF uses related to STFATE modeling. For the current analysis of Mobile Harbor O&M material, it was determined use of an alternate AF for EC50 tests was not warranted as ammonia was not isolated as the sole constituent causing potential toxicity in tested marine organisms of Mobile Harbor. Ammonia, along with BHC-lindane and other potential toxicants, was quantified in Mobile Harbor sediments that may cause larval toxicity. Instead of an alternate AF for EC50 tests, SAM analyzed environmental and typical operational controls for placement of material in the Mobile ODMDS, regardless of the constituent causing potential toxicity. To meet LPC requirements, total vessel volume was considered when determining potential operational controls required for specific placement events. Typically, vessels used for Mobile Harbor sediments range in capacity between 4,000 to 13,500 yd^3. Discussions of larger vessels added to the current hopper fleet precipitated analysis of placement options due to current sediment data analyzed. Analysis of Mobile Harbor O&M data resulted in a volume of 10,800 yd^3 as the point of operational alteration implementation. Volumes below 10,800 yd^3 would require typical vessel operation during placement activities (speed through site, doors openings, etc.). Volumes greater than 10,800 yd^3 would require specific placement operations within the ODMDS.

Using a standard AF of 0.01 for larval tests yielded volume capacities for all seven sampling reaches within Mobile Harbor to meet LPC requirements. Of the data sampled, three reaches (MH10-02, MH10-06/07, and MH10-10/11) would require vessel operation alterations when placement volumes exceeded 10,800 yd^3. Within the three reaches needing alteration, a vessel hauling greater than 10,800 yd^3 would be required to implement the following placement conditions (per STFATE modeling results and Section 103 concurrence dated 20 October 2015): place material at speeds less than 3 knots (accuracy of +/- 1 knot) per hour with no more than one hopper bin door opening simultaneously. Reaches MH10-02, MH10-06/07, and MH10-10/11 exhibited low percentage elutriate values (23, 27.3, and 23.8, respectively) resulting in restricted volumes less than 10,800 yd^3. Use of the proposed vessel operational changes, within the three aforementioned reaches, yielded no volume restrictions based on current fleet capacities or proposed future vessel dimensions (proposed to be approximately 15,000 yd^3).

Instances when use of an alternate AF is not permissible, coordination with the dredging fleet and operations staff allows some flexibility when searching for solutions to modeling results that eliminate load restrictions. Ultimately, the use and study of alternate AFs need to be discussed further with USEPA and would greatly benefit USACE placement operations serving the Nation's ODMDSs.

5.5 Discussion

Project-specific and relevant data are paramount to STFATE model optimization when assessing quantified results of sediment evaluations for ocean placement. Scow restrictions greatly inflate dredging costs; therefore, model input parameters need to be representative of environmental and operational conditions to prevent unnecessary scow volume restrictions. Reanalyzed Mobile Harbor O&M data represent an integral focal point to future decision making.

Modeling input parameters represent a snapshot of environmental and operational conditions (Table 3). These conditions define the extent to which LPC conditions are met, or exceeded, during ocean placement activities. Few parameter alterations (grid resolution, ambient velocity, and operational vessel characteristics) exert as much influence as variable EC_{50} application factors, where applicable. Resultant model output files illustrate the nature and level of influence that input parameters have on

ocean placement operations. Changes to these long-held model inputs are necessary to reflect ever-changing environmental and operational needs and requirements.

5.6 Conclusions

Applying more realistic model input parameters into STFATE resulted in the removal of dredging bin load restrictions (from 3,500 yd^3 to 20,000 yd^3) in Mobile Harbor that will save approximately $19M annually and maintain full dredge operational efficiency. The STFATE input factor having the most pronounced impact on model outcome, where appropriate, was the application factor applied to EC50 values for establishing the LPC. However, there is evidence to support instances where alternate AFs are not permissible and operational changes to placement vessels could mitigate historic load restrictions based on conservative STFATE modeling inputs. This effort would need to be closely coordinated with respective dredging fleets and District Operations staff to ensure operational parameters are attainable and reportable to USEPA to satisfy MPRSA Section 103 permit and SMMP conditions. Future work should focus on further adjusting appropriate application factors and optimizing environmental and operational parameters to best characterize actual conditions in and around ODMDSs.

6 Conclusions and Recommendations

6.1 STFATE model analysis

The STFATE sensitivity analysis indicated grid cell size can affect concentrations by at least an order of magnitude. Grid cell size is determined by the user based on ambient velocities of the subject area. From a standpoint of obtaining reasonable output (i.e., smooth concentration curves), grid cell spacing can impact model outcomes. The recommended *ambient velocity* and *grid size* pairs in the STFATE user manual are acceptable. The individual project application needs to tailor the grid cell size and ambient velocity to reflect up-to-date conditions in the project area.

Additionally, the dredging vessel or scow velocity and heading during discharge may impact concentrations in some project-specific conditions. The direction of water flow, water velocity, and variability of placement location within the site makes a difference in output values. The current guidance in the SERIM recommends setting up the placement location in the center of the site grid as a default scenario (user/guidance issue). STFATE input requires accurate/up-to-date data for ambient currents and velocities, which are not always available (user issue). Ambient current and velocity inputs apply a snapshot in time for these parameters, and applying them across a wide range of seasonal and temporal changes may not adequately represent the actual environment the model is trying to characterize.

Additionally, the coefficient ALAMDA has a dramatic impact on STFATE model output results. ALAMDA is the coefficient for horizontal diffusion of the sediment plume as it migrates through the water column. Currently, changes to this parameter are recommended on a site-specific basis. The working group is looking to assess ALAMDA for more appropriate values and use of alternate values.

Varying the placement location density gradient can have a severe effect on concentrations. The working group recommends updating the STFATE model with respect to the placement-site density gradient. The model is very sensitive to this input but doesn't respond realistically. Until the model can be made more accurate, it is recommended a constant density

profile be applied except where significant stratification occurs (a difference greater than 0.001 kg/L over a 10 m distance).

6.2 Ammonia and application factors

The working group recommends the current SERIM (USEPA/USACE 2008) be updated to include specific ammonia sensitivities among common organisms and classes of contaminants of concern and a discussion on approaches to reduce the ammonia concentrations that arise from the testing process to avoid biasing testing outcomes. Additionally, because dredge placement impacts are short in duration and application factors address long-term exposure to contaminants, it is recommended that the SERIM guidance direct users to determine and/or apply a more specific, technically defensible application factor. When ammonia is the sole cause for toxicity in elutriate bioassays, it is appropriate to apply an alternative application factor to acute toxicity data to establish the LPC. Finally, it is recommended that the NOEC generated during bioassays be adopted as LPC for embryonic development bioassays due to the extreme sensitivity and thus protectiveness of the test endpoint used.

6.3 Dredge industry input

Input from dredging industry representatives indicates that operational controls are preferred over bin and hopper restrictions. Operational controls include but are not limited to increasing or decreasing overflow during loading, placing material in zones within the ODMDS according to tide tables, adjusting vessel headings during placement relative to water current direction, and varying the bin discharge operations and options (number of bins, location of bins, sequence, etc.). It is important to communicate the nature and desired outcome of dredging constraints during construction. The dredging industry will be tasked to provide valuable insight and demonstrate capability to meet the objectives desired at an economical cost.

6.4 Application of findings, SAM

Applying more realistic input parameters into STFATE resulted in the removal of dredging bin load restrictions in the Mobile Harbor application, which will save costs and maintain full dredge fleet operational efficiency. Future work should focus on further adjusting appropriate application factors, where appropriate, and optimizing

environmental and operational parameters to best characterize actual conditions in and around ODMDSs.

Following the re-evaluation of STFATE modeling of the Mobile Harbor project, all restrictions on ODMDS placement of materials from Mobile Harbor have been removed when utilizing vessel placement operational controls in the absence of alternate AF usage. Currently, there are substantial restrictions in place for maintenance dredging of the Naval Station Mayport, Kings Bay Naval Station, and Canaveral Harbor in the SAJ and the Brunswick Harbor in the SAS. Given the positive outcomes from the SAM, it is recommended that Mayport, Kings Bay Naval Station, Canaveral Harbor, and Brunswick Harbor undergo STFATE re-evaluation. Finally, as projects require a new Section 103 concurrence from USEPA, it is recommended that the findings herein be applied.

References

ASTM International. 2012. *Standard guide for conducting static acute toxicity tests with echinoid embryos*. ASTM E1563-98(2012). West Conshohocken, PA: ASTM International.

______. 2012. *Standard guide for conducting static acute toxicity tests starting with embryos of four species of saltwater bivalve molluscs*. E724-98(2012). West Conshohocken, PA: ASTM International.

Batley G. A., and S. I. Simpson. 2009. Development of guidelines for ammonia in estuarine and marine water systems. *Marine Pollution Bulletin* 58:1472–1476.

Boardman, G. D., S. M. Starbuck, D. B. Hudgins, X. Li, and D. D. Kuhn. 2004. Toxicity of ammonia to three marine fish and three marine invertebrates. *Environmental Toxicology* 19:134–142.

Clarke, J. U., P. R. Schroeder, and J. A. Steevens. 2002. *Considerations for selection of Tier III water column toxicity standards for CDF effluent and runoff discharges: Statistical alternatives*. Environmental Effects of Dredging Technical Notes Collection. ERDC/TN EEDP-04-33. Vicksburg, MS: U.S. Army Engineer Research and Development Center. www.wes.army.mil/el/dots/eedptn.html

Hazel, R. H., C. E. Burkhead, and D. G. Huggins. 1982. Development of water quality criteria for ammonia and total residual chlorine for the protection of aquatic life in two Johnson County, Kansas streams. In *Aquatic Toxicology and Hazard Assessment,* 5th edition, ASTM STP 766, eds. J. G. Pearson, B. Foster, and W. E. Bishop, 381–388. Conshohocken, PA: ASTM.

Kennedy, A. J., G. R. Lotufo, and J. A. Steevens. 2015. *Review of dredging elutriate application factors: Relevance to acute-to-chronic protection, contaminant and endpoint specificity*. ERDC/EL TR-15-10. Vicksburg, MS: U.S. Army Engineer Research and Development Center.

Kennedy, A. J., J. H. Lindsay, J. Biedenbach, and J. D. Farrar. In preparation, a. Toxicity identification and reduction evaluation methods for elutriate toxicity tests. *Environ Toxicol Chem*.

Kennedy, A. J., J. H. Lindsay, J. Biednbach, and A. Harmon. In preparation, b. Relative sensitivity between embryo development and chronic juvenile tests to ammonia using *Mytilus* mussels. *Environ Toxicol Chem*.

Miller, D. C., S. Poucher, J. A. Cardin, and D. Hansen. 1990. The acute and chronic toxicity of ammonia to marine fish and a mysid. *Archives of Environmental Contamination and Toxicology* 19:40–48.

National Academy of Sciences (NAS)/National Academy of Engineering. 1972. *Water quality criteria*. EPA Ecological Res. Ser. EPA R3-73-033. Washington, D.C.

Thurston, R. V., R. C. Russo, and G. R. Phillips. 1983. Acute toxicity of ammonia to fathead minnows. *Transactions of the American Fisheries Society* 112:705–711.

Thurston, R. V., R. C. Russo, E. L. Meyn, and R. K. Zajdel. 1986. Chronic toxicity of ammonia to fathead minnows. *Transactions of the American Fisheries Society* 115:196–207.

U.S. Environmental Protection Agency (USEPA). 1991. *Methods for aquatic toxicity identification evaluations: Phase I toxicity characterization procedures*, 2nd edition. EPA/600/6-91/003. Washington, DC: U.S. Environmental Protection Agency, Office of Research and Development.

______. 1994. *Methods for assessing the toxicity of sediment-associated contaminants with estuarine and marine amphipods*. EPA/600/R-94/025. Washington, DC: U.S. Environmental Protection Agency, Office of Research and Development.

USEPA/U.S. Army Corps of Engineers (USACE). 1998. *Evaluation of dredged material proposed for discharge to waters of the U.S.: Inland testing manual.* EPA/823/B-98/004. Washington, DC: U.S. Environmental Protection Agency, Office of Research and Development.

______. 2008. *Southeast regional implementation manual (SERIM) for requirements and procedures for evaluation of the ocean disposal of dredged material in southeastern U.S. Atlantic and Gulf Coast Waters*. EPA 904-B-08-001. Atlanta, GA: U.S. Environmental Protection Agency Region 4 and U.S. Army Corps of Engineers, South Atlantic Division. http://www.epa.gov/region4/water/oceans/documents/SERIM_Final_August 2008.pdf

______. 2015. *Mobile ocean dredged material disposal site-Site management monitoring plan*. Atlanta, GA: U.S. Environmental Protection Agency Region 4 and U.S. Army Corps of Engineers, South Atlantic Division.

USEPA and ANAMAR Environmental Consulting, Inc. 2010. *Final report - Mobile ODMDS designation survey, Mobile, AL*. Gainesville, FL: U.S. Environmental Protection Agency Region 4 and ANAMAR Environmental Consulting, Inc.

Appendix A: STFATE Model Input Parameters for Optimization

A.1 Background

The STFATE model simulates the movement of dredged material from an instantaneous discharge as it falls through the water column, spreads over the bottom, and is transported and diffused as a plume by the ambient current. The short-term fate of dredged material placed in open water is an integral part of assessing the water-column environmental impacts. The model can provide an estimate of concentrations in the receiving water as well as the initial deposition pattern of material on the bottom. Estimates of water column concentrations are often needed to determine mixing zones. The initial deposition pattern of material on the bottom is required in long-term sediment transport studies that assess the potential for erosion, transport, and subsequent deposition of the material.

The behavior of the material is modeled as three separate phases: convective descent, during which the sediment cloud falls under the influence of gravity; dynamic collapse, occurring when the descending cloud impacts the bottom or arrives at a level of neutral buoyancy where descent is retarded and horizontal spreading dominates; and passive transport-dispersion, commencing when the material transport and spreading are determined more by ambient currents and turbulence than by the dynamics of the placement operation. During convective descent, a single cloud that maintains a hemispherical shape is released. Since the dredged material usually has low shear strength, the cloud is expected to behave as a dense liquid, thus a basic assumption is that a buoyant thermal analysis is appropriate. The flow phenomenon near the discharge opening (e.g., the bottom doors of a hopper dredge bin) is that of a sinking momentum jet. During dynamic collapse, the disposed material cloud or jet grows during convective descent as a result of entrainment. Eventually, the material reaches the bottom, or the density difference between the discharged material and the ambient water column becomes small enough for a position of neutral buoyancy to be assumed. In either case, the vertical motion is arrested, and a dynamic spreading occurs horizontally. For both an instantaneous dump from a barge and multiple discrete discharges from a hopper dredge, the basic shape assumed for the

collapsing cloud is an oblate spheroid if collapse occurs in the water column and general ellipsoid for collapse on a sloping bottom. For collapse on the bottom, a frictional force between the bottom and the collapsing cloud is included, which accounts for energy dissipation as a result of radial spreading as well as movement of the cloud centroid. When the rate of spreading in the dynamic collapse phase becomes less than an estimated rate of spreading due to turbulent diffusion in both horizontal and vertical directions, the collapsed phase is terminated. During collapse, solid particles can settle as a result of their fall velocity; other particles can be stripped from the main body of material and stored in small clouds that are characterized by a Gaussian concentration and position in the water column. At the end of each time-step, each cloud is advected horizontally by the input velocity field. In addition to the advection or transport of the cloud, the cloud grows both horizontally and vertically as a result of turbulent diffusion. Horizontal diffusion is based on the 4/3 power law. Vertical growth is achieved by employing the Fickian expression.

A.2 Program options

STFATE can be run in three modes; selection of the mode is dependent on the user's purpose for running the model:

1. General Open Water Disposal Analysis
2. Section 404(b)(1) Regulatory Analysis for U.S. Navigable Waters
3. Section 103 Regulatory Analysis for Ocean Sites

There is also a tool to determine contaminant of concern based on dilution needs for the regulatory analysis. This tool is used to select the controlling contaminant of concern (COC) for subsequent modeling based on requiring the greatest dilution.

General Open Water Disposal Analysis allows the user to model suspended solids and conservative tracer plumes as well as deposition without entering data on contaminants and placement sites or mixing zones. Section CWA 404(b)(1) Regulatory Analysis allows the user to perform mixing evaluations required by CWA 404(b)(1) regulation to meet water quality and toxicity standards, allowing the user to either specify a placement site or request computation of required mixing zone dimensions. Section 103 Regulatory Analysis allows the user to perform mixing evaluations required by MPRSA Section 103 regulations to meet water quality and toxicity criteria, which require that water quality criteria be met at all times outside

the boundaries of the placement site and inside the boundaries except within the first 4 hours after the discharge.

STFATE can be run for two different placement operations, which must be selected prior to entering data in any of the three modes. The two operations are placement from a multiple bin hopper dredge/barge and placement from a split-hull barge or dump scow. The user may switch between modes and placement operations, and STFATE will provide the data that is in common between modes and operations, but the user will need to supply the additional data that is specific to the new mode or placement operation.

For regulatory analysis, STFATE simulates the descent through the water column, collapse on the bottom, and then the passive transport and diffusion of material remaining in the water column. However, the model may be run only through the descent and collapse to examine just mound and plume development.

A.3 STFATE data needs

STFATE input consists of six data categories: Site Data, Velocity Data, Material Data, Operations Data, Execution Data, and Coefficients. The STFATE input parameters are described here, with background to assist the user in selecting appropriate values.

A.3.1 Site Data

Site data provide a description of the modeling domain, which is represented by a rectangular grid in a plan view consisting of multiple cells in the z-direction (left to right) and in the x-direction (top to bottom). The grid may be aligned in any direction, but it is generally aligned with the axis of the placement site or the predominant current direction. The length and width of the cells or spacing between grid points are specified by the user and can be based on the velocity of the receiving water, placement site dimensions and simulation duration.

A.3.1.1 Modeling domain and grid size

A maximum of 96 grid points (95 cells) in each direction is used to define the modeling domain. In the absence of site-specific needs, 65 grid points in the direction of the current and 32 points perpendicular to the current

typically provide sufficient resolution to obtain the desired spatial resolution for the evaluation. The number of grid points must be large enough to accommodate the number of long-term time-steps, offset requirements for boundaries conditions, and placement boundary offsets.

The spacing (ft) between grid points must also be specified and can be different for each direction (x-direction and z-direction). The spacing between grid points should be larger than the distance that the plume would travel in one long-term time-step in the corresponding direction. Ideally, the spacing should also be smaller than the length of the plume that encompasses all concentrations greater than 10% of the peak concentration in the plume for all periods of interest. The distance between grid points can be based on the velocity of the receiving water as shown in the Table A-1 for 4-hour simulations; spacing for shorter simulations would be proportionately smaller.

Table A-1. Grid spacing guidance.

Velocity (ft/sec)	Spacing (ft)
<0.1	20 - 50
0.1 - 0.3	40 - 150
0.3 - 0.7	100 - 300
0.7 - 1.5	200 - 500
>1.5	400 - 1000

A.3.1.2 Water depth

The user may either specify a single, constant depth of the receiving water to be used across the entire grid or else specify the water depth at each grid point. The model is typically applied using a single, constant depth, which minimizes data requirements. When using a constant depth, the user should specify the average depth of water over which the plume will travel to the regulatory compliance point; this provides a more accurate estimate of the dilution water available. When using a variable depth grid, the grid is allowed to have arbitrary areas of land (zero depth) within it, and the boundaries may be land or water; the user must be careful in selecting the placement location to ensure that it is not a land point and that the water depth is sufficient for the loaded draft of the vessel. The use of a variable depth grid in open water is generally unwarranted.

A.3.1.3 Water density profile

The water density profile is defined by providing the density at several points in the water column (minimum of two points, maximum of five). For each point, the depth and density at that depth must be supplied. Density points at the surface and water bottom must be provided. Since the same density profile is used throughout the grid, the profile must be defined to the deepest depth in the grid, even though the dump site may be much shallower. The user may elect to compute the receiving water density at each point based on salinity and temperature. Water depths must be input in order of increasing depth from top to bottom. The density is linearly interpolated between the specified depths. Vertical diffusion can be sensitive to the specified profile.

A.3.1.4 Roughness height

Roughness height is used to compute friction between the collapsing discharge and the bed as well as friction between the water column and the sediment bed. The roughness height can be estimated to be 2.5 times the D50 particle size for the sediment bed or the D85 particle size for nonuniform materials. Typical values range from 0.0005 to 0.05 ft. Roughness height tends to have an influence only on the discharge spreading during collapse.

A.3.1.5 Bottom slope

The bottom slope at the discharge point in the placement area is specified in degrees for both the x- and z-directions. The slope may either be a positive or negative value. A positive slope should be supplied if the depth increases when moving from the top of the placement grid to the bottom of the grid or from the left side of the placement grid to the right. Bottom slope tends to have an influence only on the discharge spreading during collapse and the final deposition.

A.3.2 Velocity Data

Velocity data must be supplied for the receiving waters. Although a velocity of 0.0 ft/sec can be input, it is recommended that the resultant velocity be at least 0.1 ft/sec because most open bodies of water have some motion occurring from wind, tides, and differential atmospheric pressure. Positive velocities move from the top of the grid towards the bottom (x-direction) and from left to right (z-direction). Four options, described

below, are available for specifying velocity data: Single Depth Averaged Velocity, 2-Point Velocity Profile, Variable Velocity Field, and Unsteady Velocity Profile for a Single Depth (Tidal Velocity Profile). A single depth average velocity is appropriate for most situations due to the short-term nature of the simulations.

A.3.2.1 Single Depth Averaged Velocity

The simplest velocity field to specify consists of two orthogonal velocity profiles. The user specifies a depth- and time-averaged velocity in both the x- and z-direction for a specified water depth. The velocity should represent the average over the duration of the simulation and could represent high, average, or low flow periods as deemed critical to the evaluation. Low flow conditions provide a smaller rate of dispersion and dilution but provide a longer residence time in the placement site for mixing to occur. High flow conditions provide a larger rate of dispersion and dilution but provide a shorter residence time in the placement site for mixing to occur. The critical condition is dependent on site-specific conditions including water depth, placement volume, and distance to the placement site boundary from the point of discharge. This option assumes that the flow rate at all grid points is the same and constant in time, regardless of the depth at the grid point. As such, the velocity is adjusted as a function of depth to maintain continuity. Therefore, if the depth at a grid point is 4/5 of the specified depth for the average velocity, the velocity will be computed to be 5/4 of the specified depth-averaged velocity. Additionally, the user may specify a logarithmic velocity profile to be used, which would be characteristic of uniform flow fields such as in riverine systems.

A.3.2.2 2-Point Velocity Profile

If a constant water depth has been specified in the Placement Site Data, then a 2-Point Velocity Profile may be used. This profile is used often in locations where stratified flow exists. The 2-Point profile requires the depth and velocity in the x-direction and the z-direction for two separate points. The velocity is assumed to be constant between the upper specified point and the water surface and to vary linearly from the specified velocity at the lower specified point to zero velocity at the bottom of the water column. The velocity is also assumed to vary linearly between the two specified points.

A.3.2.3 Variable Velocity Field

The user must supply the velocity in the x-direction and z-direction for each of the grid points in the model domain. In this case, velocity does not vary with time.

A.3.2.4 Unsteady Velocity for a Single Depth (Tidal Velocity Profile)

This option is same as Option 1 except that the specified velocity is not steady over the simulation duration. Time varying velocities such as those in tidal areas can be specified by the user. Velocities are calculated throughout the simulation by adjusting the velocities for the depth and interpolating the velocities between time periods. A time series of velocities is specified by the user, giving x-velocity and z-velocity at a single specified depth every half hour for 12.5 hours, representing a tidal cycle. The user specifies the time within the series when calculations begin and the duration of the simulation.

A.3.3 Material Data

Material data consists of the volume of dredged material in the dredging vessel, dredged material composition, and its condition during placement.

A.3.3.1 Dredged material volume

The volume of dredged material discharges are handled in several different manners at the discretion of the user.

Hopper

When discharging material from a hopper dredge, the user specifies the total volume of dredged material (water plus sediment), which is the sum of the individual hoppers. The volume and composition of dredged material in each hopper bin are assumed to be identical. The user describes the discharge characteristics for a hopper dredge as part of the operations data. The hopper dredge is assumed to be stationary while discharging from its bins.

Barge

When discharging material from a split hull barge or dump scow, the user has several options to specify the discharge characteristics. The user has

the option of specifying up to six discharges in the order of the releases and the velocity of the barge during each discharge to increase the spreading of the dredged material. When exercising this option, the user also has the option to specify the composition of dredged material in each discharge by selecting the separation option. In practice, control of the discharge from a barge is difficult, and it may not be practical to specify more than two discharges unless the dump scow has multiple bins. Similarly, it would be difficult to express differences in composition of multiple discharges unless the dredged material is fluid enough to allow separation of the materials.

A.3.3.2 Dredged material properties

No matter what options are used to enter the material data, the user must specify the number (up to four) of solids fractions composing the dredged material and the properties of these fractions. These properties include the solids class, the specific gravity of the solid particles, the particle fall velocity, the void ratio of the solids class after deposition, the critical shear stress required to keep the solids class in suspension, a designation as to whether particles in the solids class are cohesive and will flocculate to increase their settling velocity, a designation as to whether the particles in the solids class can be stripped and transported in the water column, and the fraction of the total volume of discharge (both particles and water) occupied by the particles in the solids class. If material separation is specified for the barge discharge, the volumetric fraction of each solids class must be specified for each discharge layer/bin. The user interface provides suggested values for properties as a function of solids fraction except the volumetric fraction, which is a function of the project instead of the solids class. Fall velocity, critical shear stress, cohesion, and stripping as well as volumetric fraction are important for predicting total suspended solids concentrations while only volumetric fraction of water (the fraction not specified as being solids) is important for predicting dilution of dissolved contaminant concentrations or elutriate.

<u>Volumetric fractions</u>

A grain size or sieve analysis typically yields the mass fraction of each particle size class after dispersing all of the material. However, dense, cohesive material with low liquidity in the barge may exist in forms other than discrete particles. For instance, materials handled with a clamshell bucket may exist as clumps in the bucket, containing water and solids at

the in situ sediment wet bulk density. Clumps should be treated as discrete particles and its own solids class. The volumetric fractions of solids represent volumes of the classes of solid particles divided by the total volume of dredged material while the volumetric fraction of water represents the volume of voids between particles and the volume of pooled water above the dredged sediment in the dredging vessel divided by the total volume of dredged material.

Clumping

The fraction of clumps can be estimated based on the water content and Atterberg liquid limit (LL) of the sediment and water entrainment during dredging. Guidance for estimating the fraction clumps and effective specific gravity is provided in Appendix A2 as well as the other solids fraction. The volume of clumps and entrained water in the barge or hopper dredge affects the amount of water (and contaminants) that is released. The dredging practice of overflowing also affects the volumetric fractions of solids fraction and water. A spreadsheet is available to aid in estimation of solids fractions.

Dredging site water density

The density of the water where it was entrained in the barge or hopper dredge must be specified. This value can be supplied or computed based on the salinity and temperature of the site water.

JBF coefficient

The user has the option to use the JBF Scientific Corporation coefficient (Holliday et al. 1978) to adjust entrainment and drag coefficients for placement from split hull barges and dump scows. This coefficient improves the computations for very fluid sediments or very dense, cohesive sediments. To use this option, the user must know the engineering water content and liquid limit of the sediment. The user specifies the ratio of the engineering water content to the liquid limit.

A.3.4 Operations Data

Operations data include the discharge location, the length and width of the discharge, the pre- and post-placement draft, and the time needed to empty the discharge vessel. This information is used to calculate the velocity of the

discharge, which affects the entrainment of water and dilution of the plume. Additionally, there is an option to confine the discharge in a depression, which is described by its length, width, and depth.

A.3.4.1 Discharge location

The location specified is the location where the discharge is initiated. Care should be taken to ensure that discharge remains in the placement site throughout the duration of the discharge and maintains at least a 300 ft offset from the up-current placement site boundary. The distance required from the down-current boundary should be determined by the modeling.

A.3.4.2 Discharge duration

The duration of the discharge is typically 1 to 5 minutes and is dependent on the size of the discharge vessel and the number of discharge bins. The duration may be increased to facilitate spreading of the discharge plume.

A.3.4.3 Vessel dimensions

The dimensions of common hopper dredges and dump scows are often available online. The properties of a number of hopper dredges are provided in Table A-2. Discharges from multibin hopper dredges often occur from pairs or groups of bins in sequence until all of the bins are empty. The user must provide the number of bins that are opened simultaneously and the number of sets of bins. The user also describes the dimension of a bin and the distance between bins as well as the pre- and post-placement drafts.

Table A-2. Hopper dredge dimensions and characteristics.

DREDGE	Capacity (yd^3)	Draft Light (ft)	Draft Loaded (ft)	Length (ft)	Beam (ft)	Max Dredging Depth (ft)	Discharge
Essayons (USACE)	6,423	22	32	350	68	94	12 doors
Wheeler (USACE)	8,400	15.5	29.5	408.3	82	80	14 doors
Yaquina (USACE)	1,050	10.3	16	200	58	55	6 doors (4 ftx4 ft)
McFarland (USACE)	3,140	15.3	23	300	72	55	
Atchafalaya	1,300	7	14	197	40	65	Split-hull, 120 ftx20 ft
Murden	512	3.8”	9.2	156	35	20	Split-hull
B.E. Lindholm	4,000		21.5	279.2	55	65	
Bayport	4,855	10	22	303	54	85	Split-hull

DREDGE	Capacity (yd³)	Draft Light (ft)	Draft Loaded (ft)	Length (ft)	Beam (ft)	Max Dredging Depth (ft)	Discharge
Columbia	4,350	8	16.5	330	50	65	
Currituck	315	3.3	7.5	150	30.6	70	Split-hull
Dodge Island	3,600	9.5	19.5	281	53	70	
Glenn Edwards	13,500	15	28	390	76	90	X doors (14 ftx21 ft)
Liberty Island	6,540		28.3	315	59	108	
Manhattan Island	3,600	9.5	19.6	281	53	70	Split-hull
Newport	4,000	8	19	265	52	60	Split-hull
Noon Island	7,325		27.9	349.7	60	78.7	
Padre Island	3,600	6	15	281	53	70	Split-hull, 190 ftx30 ft
RN Weeks	4,000		19.5	282.5	54.1	70	
Stuyvesant	9,846	17	35	372	72	131	40 doors
Sugar Island	3,600	9.5	19.7	281	53	70	Split-hull
Terrapin Island	6,400		22.3	315.6	68.4	70+	Split-hull
Westport	2,000	3	11	180	50	49	Split-hull, 160 ftx25 ft

A.3.5 Execution Data

Execution data consists of three components: simulation data, contaminant characteristics, and output options. Simulation data include the selection of the tier of regulatory evaluation, mixing zone and zone of initial dilution (ZID) dimensions and location, duration, and time-step. Contaminant characteristics include contaminant name and concentration in the discharge and background, and contaminant criteria. Output options include selection of output type, time periods, and water depths.

A.3.5.1 Tier selection

As discussed previously, the user can perform a General Open Water Disposal analysis for investigation of long-term diffusion of a tracer. Alternatively, for Section 103 or Section 404(b)(1) regulatory analysis, Tier II screening, Tier II or Tier III analyses can be performed based on the user's selection. The Tier II screen is a very conservative, worst-case evaluation that assumes all of the contaminants from the dredged material are dissolved and will be with the fluid fraction to the water column. The model needs to be run only for the contaminant requiring the greatest dilution to meet its water quality standard. This screen is solely used to

determine a need for elutriate testing or evaluation. A conservative screening tool is available for this further evaluation. The spreadsheet tool predicts the controlling COC and an elutriate concentration for the COC using equilibrium partitioning; the results can be used in a Tier II analysis to determine compliance or the need for a standard elutriate test.

A.3.5.2 Placement site/mixing zone and ZID dimensions

The placement site, mixing zone, or ZID is treated as a rectangle whose sides are parallel to the sides of the model grid. The location of the placement site on the model grid must be provided. The location of the upper left and lower right corners of the rectangle are specified by their distances in feet from the top edge and left edge of the grid. Under Section 404(b)(1) regulatory analysis, STFATE will compute the minimum size of the mixing zone that will comply with the water quality standard if zeroes are entered for the distances to the corners.

Ideally, the length of the mixing zone/placement site and the model grid are aligned with the direction of the dominant current. If not, the model grid should be aligned with the placement site/mixing zone. If the placement site is not rectangular, the user should fit a rectangle inside the designated placement site. The user should create the longest rectangle dimension aligned with the current direction with the placement point on the center-line of the rectangle having a width of approximately 600 ft to 1000 ft.

A.3.5.3 Simulation duration

The duration of the simulation must be specified in seconds. The duration should be sufficient for the plume to pass completely through the placement site or mixing zone or to be diluted to meet the water column criterion everywhere (generally 30 minutes to 6 hours). As an estimate, the duration should be approximately 25% greater than the length of the flow path from the discharge point to the placement site/mixing zone boundary divided by the near-bottom velocity. For a Section 103 regulatory analysis, duration of 14,400 sec should be specified for water column toxicity evaluations. Ideally, the duration in seconds should be evenly divisible by 40 to facilitate specifying output time periods and long-term time-steps.

A.3.5.4 Simulation long-term time-step

The long-term (computational) time-step for transport-diffusion calculations (sec) must also be specified. Presently, STFATE is limited to 40 time-steps. Therefore, to obtain the maximum resolution in the results, the time-step should be 1/40 of the simulation duration. The time-step is generally selected so that a small cloud does not travel more than the length or width of one model grid cell during the time-step.

A.3.5.5 Contaminant characteristics

For Tier II analysis, the user specifies the name of the contaminant of concern. For Tier III analysis, the COC is FLUID.

<u>Contaminant concentration</u>

For Tier II screening analysis, the user specifies the bulk sediment concentration of the COC in units of mg/kg. For Tier II water quality analysis, the user specifies the concentration of the COC in mg/L from the standard elutriate test or an estimate of the elutriate concentration from elutriate screening analysis. For Tier III toxicity analysis, the STFATE model uses 100% elutriate for the fluid fraction.

<u>Contaminant criteria</u>

For modeling discrete discharges lasting fewer than 15 minutes that are separated by at least a couple of hours as modeled by STFATE for Tier II evaluations, the user specifies the water quality criteria for protection of aquatic organisms from acute toxicity by the COC. For Tier III toxicity analysis, the user specifies the lowest resultant product of the LC50s (multiple LC50s may exist from testing several classes of organisms) and the corresponding application factors (typically, 0.01) in percent. If water column bioassay testing of the standard elutriate failed to produce an LC50 but some toxicity in excess of the control was observed, the user should select the NOEC, or less conservatively the lowest observed effects level (LOEL), else most conservatively the user could assume an LC50 of 100% and use it to compute the product of the LC50 and the corresponding application factor (typically, 0.01) in percent. In the absence of any observed toxicity, no Tier III evaluation is required.

A.3.5.6 Output

Generally, the results of all phases of simulation should be printed to better understand the impacts of the dominant processes.

Output print times

Detailed results for the transport-diffusion simulation are reported quarterly during the simulation for all solids fraction and the contaminant, tracer or fluid unless specific print times are requested for detailed results; up to 12 print times may be requested. Ideally, the print times should be a multiple of the long-term time-step. Summary results for the contaminant, tracer, or fluid fraction are produced for each long-term time-step, while summary results for the solids fractions are produced only for the specified print times.

Output locations

Detailed and summary results for the transport-diffusion simulation of all solids fractions and contamination are reported at up to five depths in the water column as requested by the user. Three depths are generally sufficient to capture the plume behavior: a near-bottom location such as 1 ft above the bottom; an upper water column depth at the depth of the loaded draft where the material is released; and a mid-depth point halfway between the upper and near-bottom points. In addition to the specified depths, the STFATE model reports a summary at five additional depths in an attempt to identify the peak contaminant concentration in the water column.

A.3.6 Coefficients

A number of coefficients are utilized within STFATE as listed in the Table A-3. In general, the default coefficients are sufficient for most applications. However, other values can be entered. Computer experimentation such as that presented by Johnson and Holliday (1978) has shown that model results appear to be fairly insensitive to many of the coefficients. The coefficients are described below.

Table A-3. STFATE coefficients with keyword and default value.

	Description	Keyword	Default Value
1	Settling coefficient	BETA	0.00
2	Apparent mass coefficient	CM	1.00
3	Drag coefficient for a sphere	CD	0.50000
4	Form drag for collapsing cloud	CDRAG	1.00
5	Skin friction for collapsing cloud	CFRIC	0.01
6	Drag for an ellipsoidal wedge	CD3	0.10
7	Drag for a plate	CD4	1.00
8	Friction between cloud and bottom	FRICTN	0.01
9	4/3 Law horizontal diff. dissipation factor	ALAMDA	0.00100
10	Unstratified water vertical diff. coefficient	AKY0	0.02500
11	Ratio-Cloud/Ambient density gradients	GAMA	0.25
12	Turbulent thermal entrainment	ALPHA0	0.235
13	Entrainment in collapse	ALPHAC	0.10000
14	Stripping factor	CSTRIP	0.00300

The settling coefficient, BETA, is taken from Koh and Chang (1973). The default value is expected to be good for low solids concentrations. No guidance is available on how to adjust the value. The value should not impact contaminant concentrations in the water column.

The added mass coefficient (CM) is supplied by Koh and Chang (1973). It is used to calculate an inertia force and varies from 1 to 2. The value 1 represents an undisturbed water column. The value should not impact contaminant concentrations in the water column.

Drag coefficients are taken from Koh and Chang (1973). Initially, the cloud is considered a hemisphere with drag calculated as that of a sphere. When the cloud encounters neutral buoyancy, its shape is instantly transformed from a hemisphere to an oblate spheroid. If the descending hemispherical cloud hits the bottom, the shape of the cloud is instantly transformed to an upper half oblate spheroid. CD is the drag coefficient for a sphere in the expected range of Reynolds numbers. CD3 is the drag coefficient for a spheroidal wedge, used to compute drag force in the x- and z-directions, and CD4 is the drag coefficient for a circular plate normal to flow, used to compute drag force in the y-direction. The default values for these drag coefficients were obtained from diagrams presented in Hoerner (1965) for solid shapes in fluid, and as such, are not strictly applicable to this work.

The drag coefficients impact the settling rate of the discharge plume and the rate and extent of the collapse of the discharge. As such, it impacts the entrainment of water into the discharge prior to passive transport and diffusion. Large drag coefficients should decrease initial dilution. The drag coefficients may be somewhat lower than the default value because the discharge will deform and provide less resistance or drag than solid shapes. Therefore, the coefficients are conservative. Verification studies yielded results in general agreement with the model predictions for the descent and collapse phases using default coefficients.

CDRAG, the drag coefficient for an elliptic cylinder edge into the flow, is based on educated guess presented by Koh and Chang (1973), as are CFRIC and FRICTN. CDRAG and CFRIC are used to compute the form drag and skin friction drag, which are the forces resisting collapse of the cloud. As with the other drag coefficients, large drag coefficients should decrease initial dilution. The drag coefficients may be somewhat lower than the default value because the discharge will deform and provide less resistance or drag than solid shapes. Therefore, the coefficients are conservative. Verification studies yielded results in general agreement with the model predictions for the descent and collapse phases using default coefficients.

CFRIC, skin friction coefficient, or friction coefficient for a flat plate, is also based on educated guess presented by Koh and Chang (1973). The coefficient affects only the collapse of the discharge on the bottom or in the water column.

FRICTN is a bottom friction coefficient and is again based on educated guess presented by Koh and Chang (1973). The coefficient affects only the collapse of the discharge on the bottom.

The 4/3 Law horizontal diffusion dissipation factor, ALAMDA, is applicable to the general trend of horizontal diffusion which follows a 4/3 power law: $K_x = A_L L^{4/3}$, where K_x is the horizontal diffusion coefficient, A_L is a constant called the dissipation parameter (ft$^{2/3}$/sec), and L is horizontal scale. The value of A_L ranges from 0.005 to 0.00015 ft$^{2/3}$/sec (Brandsma and Divoky 1976). ALAMDA is expected to be somewhat higher in an estuary. The default value is appropriate except for very high-resolution grids, which would use a larger value.

The maximum value for the vertical diffusion coefficient, AKY0, has been estimated to be 0.05 ft²/sec (Brandsma and Divoky 1976). An option is available to calculate AKY0 using Pritchard Expression instead of the default or user-specified value. The expression is more appropriate in an estuary.

GAMA is introduced by Koh and Chang (1973) to simulate the effect of density gradient differences in causing cloud collapse. The default value is based on an educated guess.

ALPHAO is the entrainment coefficient for a turbulent thermal determined experimentally by Koh and Chang (1973). The entrainment coefficient associated with the entrainment of ambient fluid into the descending hemispherical cloud is assumed to vary smoothly between its value for a vortex ring and the value for turbulent thermals. Model results are quite sensitive to the entrainment coefficient, which in turn is dependent upon the material being disposed (the higher the moisture content, the larger the value of the entrainment coefficient) (Johnson 1990).

ALPHAC is the coefficient for entrainment due to cloud collapse given by Koh and Chang (1973).

A.4 Calculation of clumping

STFATE requires sediment concentrations in volumetric units (volume of solids particles per total volume).

Commonly, concentration (*C*) is reported as percent solids by weight (*W*):

$$Concentration, C = 100\% \times \left(W_{solids} / W_{total}\right) \tag{1}$$

or as engineering water content that can be calculated in grams or as a percent:

$$Engineering\ water\ content = 100\% \times \left(\frac{W_{water}\left(in\ grams\right)}{100\ grams\ of\ dry\ solids}\right) \tag{2}$$

Percent moisture is 100% - percent solids. Atterberg limits (liquid and plastic limits) are given as water contents.

To convert water content (w) in percent to percent solids (%S):

$$\%S = 100\% / \left[\left(w / 100\% \right) + 1 \right] \tag{3}$$

To convert percent solids (%S) to water content (w) in percent:

$$w = 100\% \times \left(100\% - \%S \right) / \%S \tag{4}$$

Given liquid limit (LL), %Coarse, %Silt, and %Clay by weight, and specific gravities (SG) of the solid fractions, where %Coarse is 100% times the mass of dry sands and gravels divided by the total mass of dry solids, the volumetric concentration of clumps and effective volumetric concentrations of coarse (sand and gravel), silt and clay fractions are computed as follows:

1. First, compute the engineering water content (w) of the sediment.
2. Second, compute the percent clumps in the sediment as follows:

   If $w > 1.8\,LL$, percent clumps equal 0%.

   If $w < LL$, percent clumps equal 100%; otherwise,

$$\%Clumps = 100\% \times \left\{ \left[1.8 - \left(w / LL \right) \right] / 0.8 \right\} \tag{5}$$

3. Third, compute effective SG of the total solids.

$$\begin{aligned} &SG_{effective} \\ &= \left[\left(\%Coarse \times SG_{coarse} \right) + \left(\%Silt \times SG_{silt} \right) + \left(\%Clay \times SG_{clay} \right) \right] / 100\% \end{aligned} \tag{6}$$

4. Fourth, compute solids concentration of sediment in kg/L.

$$C_{solids}, kg / L = 100 / \left[\left(100 / SG_{effective} \right) + \left(100 \times w / 100\% \right) \right] \tag{7}$$

5. Fifth, compute concentrations in barge in kg/L.

   Assuming that the barge content is 90% sediment and 10% entrained water, then the solids concentrations are computed as follows:

$$C_{barge} = \left(90\% / 100\% \right) \times C_{solids} \tag{8}$$

$$C_{clumps} = \left(\%Clumps / 100\%\right) \times C_{barge} \tag{9}$$

$$C_{coarse} = \left(C_{barge} - C_{clumps}\right) \times \%Coarse / 100\% \tag{10}$$

$$C_{silt} = \left(C_{barge} - C_{clumps}\right) \times \%Silt / 100\% \tag{11}$$

$$C_{clay} = \left(C_{barge} - C_{clumps}\right) \times \%Clay / 100\% \tag{12}$$

6. Sixth, compute volumetric fractions of components.

   Assuming that the barge content is 90% sediment and 10% entrained water, then the volumetric fractions are computed as follows:

$$F_{clumps} = 90\% / 100\% \times \%Clumps / 100\% \tag{13}$$

$$F_{coarse} = C_{coarse} / SG_{coarse} \tag{14}$$

$$F_{silt} = C_{silt} / SG_{silt} \tag{15}$$

$$F_{clay} = C_{clay} / SG_{clay} \tag{16}$$

$$F_{fines} = F_{silt} + F_{clay} \tag{17}$$

$$F_{water} = 1.00 - F_{clumps} - F_{coarse} - F_{silt} - F_{clay} \tag{18}$$

7. Seventh, compute specific gravity of clumps.

$$SG_{clumps} = \left[\left(w / 100\%\right) + 1\right] / \left[\left(w / 100\%\right) + \left(1 / SG_{effective}\right)\right] \tag{19}$$

A.5 Example calculation for clumping

a. Sediment conditions

Given the following sediment properties:

- 0.92% gravel
- 27.54% sand
- 41.7% silt

- 28.8% clay
- 44% moisture by weight or 56% solids by weight
- Liquid limit (*LL*) 48.8% (water content)
- Effective specific gravity (*SG*) 2.50

b. Clumping calculation

If the sediment is 44% water, then the engineering moisture content using Equation (2) is

Step 1: $Engineering\ water\ content,\ w = 100\% \times \left(\dfrac{44\%\ water}{56\%\ solids}\right) = 78.6\%$

Next, using the liquid limit provided from Atterburg laboratory test results, find the percent of clumps in the sediment using Equation (5).

Step 2: $\%Clumps = 100\% \times \left\{\left[1.8 - \left(78.6\% / 48.8\%\right)\right] / 0.8\right\} = 0.237\, or\, 23.7\%$

The effective SG is provided in this example, so Equation (6) is not needed and,

Step 3: $SG_{effective}$ = 2.50.

In the event that the effective SG needs to be calculated, laboratory tests for the SG of each of the sediment fractions will need to be completed.

Next, find the solids concentration C_{solids} inside the barge that includes both sediment and water using Equation (7):

Step 4: $C_{solids}, kg / L = 100 / \left[\left(100 / 2.50\right) + \left(100 \times 78.6\% / 100\%\right)\right] = 0.843\, kg / L$

c. Volumetric solids concentration calculations

Assume that the barge content is 90% sediment and 10% entrained water. If the solids concentration is 0.845 kg/L in the sediment and it is 90% sediment, and the coarse fraction is the sum of the gravel and sand fractions (28.46%), then the total solids concentrations for each fraction is found using Equations (8) through (12):

$$C_{barge(sediment)} = (90\% / 100\%) \times 0.845 kg / L = 0.761\ kg / L$$

$$C_{clumps} = (23.8\% / 100\%) \times 0.761 kg / L = 0.181 kg / L$$

Step 5: $C_{coarse} = (0.761 kg / L - 0.181 kg / L) \times 28.46\% / 100\% = 0.165 kg / L$

$$C_{silt} = (0.761 kg / L - 0.181 kg / L) \times 41.7\% / 100\% = 0.242 kg / L$$

$$C_{clay} = (0.761 kg / L - 0.181 kg / L) \times 28.8\% / 100\% = 0.167 kg / L$$

Using the sediments effective specific gravity of 2.50, the total solids volumetric concentration is found. If 23.8% of the solids are in clumps, the volumetric clump fraction using Equation (13) is

Step 6: $F_{clumps} = 90\% / 100\% \times 23.8\% / 100\% = 21.4\% or\, 0.214$

The material is 0.92% Gravel and 27.54% Sand so the coarse fraction is 28.46% of the remaining solids fraction. The fine fraction is 71.54% (41.7% Silt and 28.8% Clay) of the remaining solids fraction. The volumetric solids fractions for the coarse, fine, and water fractions are

$$F_{coarse} = (0.165 / 2.5) = 0.066$$

$$F_{fines\,(silt\ and\ clay)} = (0.242 + 0.167) / 2.5 = 0.164$$

$$F_{water} = 1.00 - 0.214 - 0.066 - 0.164 = 0.556$$

d. SG of clumps

Finally, the SG of the clumps using Equation (20) is

Step 7: $SG_{clumps} = [(78.6 / 100\%) + 1] / [(78.6 / 100\%) + (1 / 2.5)] = 1.506$

A.6 References for Appendix A

Brandsma, M. G., and D. J. Divoky. 1976. *Development of models for prediction of short-term fate of dredged material discharged in the estuarine environment.* Contract Report D-76-5. Prepared by Tetra Tech, Inc., Pasadena, CA. Vicksburg, MS: U.S. Army Engineer Waterways Experiment Station.

Hoerner, S. F. 1965. *Fluid dynamic drag*. Brick Town, NJ: S. F. Hoerner.

Holliday, B. W., B. H. Johnson, and W. A. Thomas. 1978. *Predicting and monitoring dredged material movement*. Technical Report DS-78-3. Vicksburg, MS: U.S. Army Engineer Waterways Experiment Station.

Johnson, B. H., and B. W. Holliday. 1978. *Evaluation and calibration of the tetra tech dredged material disposal models based on field data*. Technical Report D-78-47. Vicksburg, MS: U.S. Army Engineer Waterways Experiment Station.

Johnson, B. H. 1990. *User's guide for models of dredged material disposal in open water*. Technical Report D-90-5. Vicksburg, MS: U.S. Army Engineer Waterways Experiment Station.

Koh, R. C. Y., and Y. C. Chang. 1973. *Mathematical model for barged ocean disposal of waste*. Technical Series EPA 660/2-73-029. Washington, DC: U.S. Environmental Protection Agency.

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. REPORT DATE	**2. REPORT TYPE**	**3. DATES COVERED** *(From - To)*
March 2016	Technical Report	

4. TITLE AND SUBTITLE
Ocean Dredged Material Disposal Site (ODMDS) Authorization and Short Term FATE (STFATE) Model Analysis: 2014-2015 Working Group Findings Report

5a. CONTRACT NUMBER

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)
Jase D. Ousley, Paul R. Schroeder, Susan Bailey, Alan Kennedy, and Matthew J. Lang

5d. PROJECT NUMBER

5e. TASK NUMBER

5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Coastal and Hydraulics Laboratory
Engineer Research and Development Center
3909 Halls Ferry Road, Vicksburg MS 39180

8. PERFORMING ORGANIZATION REPORT NUMBER
ERDC TR-16-2

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
South Atlantic Division
US Army Corps of Engineers
60 Forsyth Street, Atlanta GA 30303

10. SPONSOR/MONITOR'S ACRONYM(S)

11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution is unlimited.

13. SUPPLEMENTARY NOTES

14. ABSTRACT
The U.S. Army Corps of Engineers (USACE) dredges hundreds of millions of cubic yards of sediment from Federal ports, harbors and waterways annually. The USACE Navigation Data Center reports on average 42% of dredged material is placed offshore in Offshore Dredged Material Disposal Sites (ODMDS). Regulation of dredged material placement within waters of the United States and ocean waters is a shared responsibility of the USACE and U.S. Environmental Protection Agency (USEPA) under the Marine Protection, Research, and Sanctuaries Act (MPRSA, also called the Ocean Dumping Act) and the Clean Water Act (CWA). Dredged sediments placed offshore must have limited contaminants and be shown to have minimal impact on benthic species. The Short-Term FATE of dredged material placed in open water (STFATE) model was created by USACE to assist with dredge material placement impact assessment. STFATE enables the computation of the physical fate of dredged material disposed in open water and simulates the movement of the disposed material as it falls through a water column, spreads over the bottom and is transported and diffused as suspended sediment by the ambient current. In 2013, STFATE model outputs resulted in operational restrictions on several projects in USACE districts in the South Atlantic Division (SAD) region. A working group was established to address operational restrictions such as dredging vessel bin load restrictions, restricted release zones and other issues that impacted the efficiency and cost of dredging. The working group evaluated the sensitivity of inputs into the STFATE model and found grid cell size, dredge vessel velocity and heading, water density gradient, and application factors all had significant impacts on model output. The working group found that applying a more specific, technically defensible application factor produced model outputs that result in unrestricted dredging operations in USACE Mobile District, Mobile Harbor O&M project. Given the positive outcomes from the Mobile District, it is recommended that other USACE projects with operational restrictions undergo STFATE re-evaluation. Finally, as projects require a new MPRSA and CWA concurrence from USEPA, it is recommended that the findings here in be applied.

15. SUBJECT TERMS
Ammonia, Marine Protection research and Sanctuaries Act, Navigation, Offshore Disposal, Offshore Dredged Material Disposal Sites, Operational Dredge Controls, STFATE, US Army Corps of Engineers, US Environmental Protection Agency

16. SECURITY CLASSIFICATION OF:			**17. LIMITATION OF ABSTRACT**	**18. NUMBER OF PAGES**	**19a. NAME OF RESPONSIBLE PERSON**
a. REPORT	**b. ABSTRACT**	**c. THIS PAGE**			**Jase D. Ousley**
Unclassified	**Unclassified**	**Unclassified**	**SAR**	59	**19b. TELEPHONE NUMBER** *(Include area code)* **601-634-6044**